

RFI ATTENUATING MATERIALS
AND STRUCTURES
AN ANALYSIS AND CONCEPTUAL
DESIGN

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FOREWORD

This is the final report on a project to study material shielding effectiveness, shelter conceptual design, and cost effectiveness analysis of permanent and portable RFI shelters. Work was performed for APFH, Wright-Patterson AFB, under contract F33615-68-C-1206, project 8174, during the period January 1968 through December 1968. This report was submitted in July 1969.

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Many of the items compared in this report were commercial items that were not developed or manufactured to meet Government specifications, to withstand the tests to which they were subjected, or to operate as applied during this study. Any failure to meet the objectives of this study is no reflection on any of the commercial items discussed herein or on any manufacturer. Acceptable performance does not constitute an endorsement of any manufacturer or product.

This technical report has been reviewed and is approved.

Approved:



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ABSTRACT

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RFI attenuating materials and construction methods for portable and permanent shelters are discussed and found to be inadequate for high levels of attenuation, even though satisfactory performance may be obtained for lower levels of attenuation. Measurement techniques and test fixtures are developed to permit rapid evaluation of shielding effectiveness of about 100 samples of various materials, including base metals, composites, screens and foils. Test results are presented that permit selection of suitable materials for each level of attenuation desired. Representative samples of commercial enclosures are tested for seam integrity, access opening and door leakage, and overall construction methods. Weaknesses of all the standard assembly methods are discussed in detail. Conceptual designs are developed that apply the materials and construction methods defined to each level of attenuation and type of enclosure. Detailed drawings and specifications are presented for each configuration. A comparison is made between each class of enclosure for weight, volume, erection time and cost for each level of attenuation. Discussions are presented of trade-offs and simplifications for each attenuation level and type of shelter.

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SECTION I

INTRODUCTION

GENERAL

Military installations often require the use of permanent or portable shelters for protection of men and equipment from the environment. In addition, electronic equipment must often be operated in an RFI-free enclosure to meet the needs for Electromagnetic Compatibility (EMC).

Present construction techniques usually call for the addition of an appropriate RFI shielding material to an existing shelter. Since shielding is installed after shelter erection, costs and erection time may become excessive. The resulting enclosure is frequently unreliable and not of a portable nature.

PROGRAM OBJECTIVES

The objectives of this study and design program may be broken down into three areas:

1. Select suitable RFI shielding material and appropriate joining methods for use with portable and permanent shelters.
2. Perform conceptual designs for permanent and portable shelters based upon the required RFI attenuation and other specifications for the shelters.
3. Analyze the selected materials and designs from a cost/effectiveness standpoint, including the various tradeoffs between cost, erection time, attenuation level, and enclosure configuration.

SCOPE

This report contains the results of a program to study shielding materials, joining techniques, enclosure construction, and cost/effectiveness considerations. Information will be presented on each of these topics in a separate section of the report.

Section II describes material and enclosure test methods, as well as results of various evaluations that were conducted. The conceptual design phase of the study is contained in Section III.

Recommendations for shelter configuration and materials will be found in the last section (Section IV) of the report. Cost/effectiveness study data is also in Section IV. Test data (graphs), a list of materials tested, references, and a list of sources of RFI shielding materials will be found in the Appendix.

SECTION II

MATERIAL AND STRUCTURE EVALUATIONS

1. LABORATORY TECHNIQUES FOR SHIELDING EVALUATIONS

This portion of the report will describe the test methods developed and applied to evaluate RFI shielding materials and joining techniques. Definitions of terminology employed will be included where appropriate.

A. Shielding Effectiveness

The amount of attenuation occurring when RF radiation attempts to pass through a barrier is known as the shielding effectiveness of that barrier. Shielding effectiveness (SE) may be determined by measuring the electromagnetic field intensity before and after the insertion of a barrier between the RF source and measuring instrument.

A general form of the equation for shielding effectiveness (SE) is:

$$\begin{aligned} \text{SE in DB} &= 20 \log V_1/V_2 \\ V_1 &= \text{field intensity without barrier} \\ V_2 &= \text{field intensity with barrier.} \end{aligned} \quad (1)$$

Practical application of this equation in tests for SE is difficult to accomplish due to effects of leakage around the barrier, reflections, and ground loops. Measurement techniques and special test fixtures were developed by Genistron to permit proper evaluation of shielding effectiveness.

The frequency range and levels of attenuation shown in figure 1* will be used for the evaluation of various materials and enclosures. These limits are basically intended to conform to class B and C levels from Table II of MIL-E-8881A (1);** and to NSA specification #65-6 (2).

B. Cylindrical Test Fixture

One type of test fixture developed for SE testing is shown in Figures 2 and 3. RFI samples up to 14" x 14" may be evaluated in this fixture. The significant features of the cylindrical test fixture are:

*Figures will be found in appendix I.

**References will be found in appendix V.

1. Size and portability are such that a large number of samples may be rapidly evaluated.
2. Small defects in items intended for shielding will be readily apparent in the small size fixture.

Shielding effectiveness is determined in the following manner. The two halves of the fixture are placed against each other, aligned, and clamped with heavy duty C clamps. The voltage measured without any shielding material is recorded as V1. To evaluate a sample, the test fixture halves are separated and the sample clamped securely between the fixture halves. With the shield interposed in the radiated field, the sense probe voltage V2 is recorded and SE calculated as shown in equation (1) above.

This technique, though not strictly described by MIL-STD-285 (3), is compatible with that standard. The primary differences are in the size and separation of the loop antennas (H field evaluations) and the type and separation of antenna used for E field measurements. These differences effect the ratio of tangential to normal field components in a given test region and type of field. Measurements may be correlated by giving consideration to the effects of the two field components independently.

C. Test Fixture Using Shielded Room Wall

Genistron Division, Genisco Technology Corporation, has modified a wall in one of their double-panel steel shielded rooms to accommodate tests of shielding materials. A typical high frequency test set-up is shown in Figure 4, while Figure 5 shows a close-up view of the 3'x3' cut out panel. Samples of reasonable size may be evaluated for shielding effectiveness at various frequencies, using this panel.

The thickness of the 3'x3' plate was selected to provide much greater attenuation than the SE of any sample to be tested. To prevent leakage, mounting screws are spaced at six inch intervals to provide proper closure, and steel wool RFI gasketing is used as required. The standard antennas of MIL-STD-285 can be used with this fixture.

D. Test Fixture Agreement

Measurements have been made to illustrate the level of agreement between the cylindrical and wall test fixtures. Data in Figure 6 for copper and Figure 7 for galvanized steel demonstrates the agreement between tests in each fixture with calculated levels. Note that the combined accuracy of the calibrated instrumentation system (transmitter-receiver) is approximately 3 to 4 DB.

E. Dynamic Range

Dynamic range may be defined as the useful measurement capability of any given instrument or test set-up. The limiting factors in a measurement set-up are often the internal noise levels in signal detection equipment. This was the case in the test setups used to evaluate shielding effectiveness of materials.

Figure 8 shows the dynamic range encountered during SE evaluations. In the E field region, 100 KHz to 100 MHz, system noise limits the sensitivity to 120 to 140 DB which is in some cases less than the Class II limits (Figure 1). However, measurements in this frequency range were satisfactory for the SE evaluations, as shown below.

Internal noise in an RI-FI meter is of a random nature since it results from thermal agitation, shot effect, and other component-related noise sources. A signal when observed against this random noise background may be described as possessing a certain ratio of signal plus noise to noise voltage. When the S+N/N ratio approaches zero, the dynamic range of the instrument is reached.

It has been shown (6) that the level of such a "noisy" signal may be corrected for the effects of the noise in the following manner. The signal level may be determined by performing an RMS subtraction as shown below.

Desired signal = $(\text{signal} + \text{noise})^2 - (\text{noise})^2$ (2)
where all parameters are expressed in DB as read from the RI-FI meter.

For example a S+N/N ratio of .5 DB would result in a "Correction factor" of 9.6 DB. The application of this 9.6 DB factor to the E field dynamic range of Figure 8 demonstrates that the instrumentation is adequate for the assigned task.

F. Grounding

To properly instrument the shielding test set-up, it was necessary to use a single point ground. This ground point may be located at the test fixture or at the shielded room wall if the test fixture is within two feet of the wall.

The power cords on the receiver and signal generator were isolated from ground. This prevented ground loops that could invalidate the tests.

G. Leakage

As mentioned previously, leakage around the test sample will cause erroneous readings for SE. This leakage may occur in any of three ways, as discussed in the following paragraphs.

High level fields radiating from the enclosure or signal generator output cable may couple by direct radiation into the receiver or its input cable. This problem is most critical for low frequency (10 Hz through 1 MHz) magnetic field testing, and also for microwave testing from 1 to 10 GHz. Energy leakage in this mode was prevented by locating the signal generator in a separate shielded enclosure. Signals were fed to the test fixture through the wall, using feed-through type coaxial connectors. Solid coaxial cable was used to prevent radiation, since all current is contained inside the shield.

It is possible for signals to pass through the power cords of a signal generator and receiver that are connected to the same power source. If the signal generator is placed in a separate screen room, any signals on the power cord must pass through two screen room filters before they get to the receiver. Each of the filters will then provide 100 DB of attenuation, eliminating power line coupling as a source of leakage.

The third method of leakage could be internal radiation around the test sample inside of the test fixture. Fixture design eliminated this possibility by using the heavy duty C clamps to hold the fixture together.

Under extensive evaluation, no leakage was detected above the receiver background noise level. During this test, a 100 mil steel shield was substituted for the test sample.

Certain test samples required the use of steel wool RFI gasketing on each half of the fixture, prior to sealing. This completed the isolation, which was required for some magnetic field testing from 100 Hz to 14 KHz.

2. LABORATORY EVALUATION OF SE FOR INCIDENT E FIELDS

Each test sample was evaluated using the test set-up shown in Figure 9 (4). A disc antenna (100 Hz to 1 GHz) at a test distance of two or twelve inches was used for the majority of tests. Signal generators were selected for their high output voltage capability.

In this test set-up, the generated field polarity is established between the transmitting plate and the plate in which the test sample is mounted. The resulting field is similar to that existing between the plates of a parallel plate capacitor. This field is perpendicular to the plane of the test sample.

There is also present in this configuration a vertical component of the E field that is generated by the loading effects of the walls of the cylindrical test fixture. The two fields present are equivalent to those found in the near zone of a vertical rod antenna of the type normally used for RFI testing.

In reality, it is the horizontal component of the E field that creates a potential difference across the shield. This in turn produces a current flow in the test sample. Shielding evaluations are then conducted under worst case conditions, in the near field of the antennas.

The attenuation of base metal samples inherently is greater than the E field limits of Figure 1. For this reason, base metals were not subjected to extensive laboratory evaluation. However, E field tests on seams and access configurations are important as leakage becomes a problem, particularly above 500 KHz. These enclosure and seam tests will be described in Section II-5 and II-6 of this report.

3. LABORATORY EVALUATION OF SE FOR INCIDENT H FIELDS

The results of magnetic (H) field testing on sheet metal samples determine both the material type and thickness required for shelter construction. Samples were evaluated in the test set-up of Figure 9 (4), using 12" and 1" diameter loop antennas in the wall test fixture. In the cylindrical test fixture, loop antennas of 3" and 1" diameter were employed.

A test distance of 2" was used in each fixture. The axis of the loop was oriented parallel to the plane of the sample being tested, in order to maximize the field intensity and thereby evaluate SE under worst case conditions. A detailed discussion of field intensity calibration and measurement techniques, including the effects of saturation and various field intensities, will be found in the following topics.

A. Constant Field Intensity

It is important to subject each test sample to a constant field intensity over a wide range of frequencies. In such a fixed field, the permeability will remain constant so that the effect of changing frequency on SE will be observed.

If a constant field intensity is not maintained, a variation of permeability with frequency will occur simultaneously with the variation in attenuation due to changing flux density, and neither variation will be explicit. Test methods used to insure a constant field intensity are described below.

B. Magnetic Field Measurement

Samples of ferrous metals to be evaluated for SE were subjected to various field intensities in order to understand the change in permeability due to saturation of the material. To do this, it was necessary to measure and to calculate the field at the surface of the metal.

The approach taken was to first calculate the field existing at close proximity to a small radiating loop antenna. A sensor probe was then used to measure the field intensity, and the calculated and observed values compared.

Shelkunoff (5) has described the exact field resulting from current flowing in a loop. The following equations may be used to compute the E and H fields radiated by the test loop:

$$E_{\phi} = \frac{n\beta NIA}{4\pi r^2} [1 + j\beta r] e^{-j\beta r} \sin \theta, \text{ in volts/meter}$$

$$H_{\theta} = \frac{NIA}{4\pi r^3} [1 + j\beta r - (\beta r)^2] e^{-j\beta r} \sin \theta, \text{ in amperes/meter}$$

$$H_r = \frac{NIA}{2\pi r^3} [1 + j\beta r] e^{-j\beta r} \cos \theta, \text{ in amperes/meter}$$

where:

$n = 376.7$ ohms

$\beta = 2\pi/\lambda$

$r =$ distance from loop to antennas, in meters

$A =$ loop area in square meters

$I =$ loop current in amperes

$N =$ number of turns in loop

Figure 11 depicts the fields described by these equations.

A Hall Effect probe (Hallflex #1568 Magnetic Field Sensor), in the circuit shown in Figure 10, was used to measure field intensities. The output voltage is directly proportional to flux density, for various levels of loop current.

C. Comparison of Measured and Calculated Fields

Measured and calculated values for field intensity are compared in Figure 12. Tests were performed using one of the source antennas that was used for SE evaluations. The loop was 1" diameter and had 100 turns. Test distances were 1, 2 and 12".

When the current driving the source antenna is measured during magnetic field shielding tests, Figures 12 and 13 can be used to obtain the field intensity that the sample is subjected to at a known test distance by simply measuring the loop current. This technique was employed during magnetic field shielding effectiveness evaluations.

D. Relative Permeability

The conductivity and permeability of ferrous materials versus applied flux density are some of the properties of basic materials that are not readily available. These properties can be very useful in the prediction of shielding efficiency for a given ferrous material.

Theoretical approaches to conductivity and permeability measurements, and detailed test methods will be found in Appendix II.

This completes the discussion of shielding evaluation techniques, definitions, and preliminary tests and calibrations. The next section of the report will deal with the results of material testing, seam and closure evaluations, and observations of shielding effectiveness of existing RFI enclosures.

4. RESULTS OF SHIELDING MATERIAL EVALUATIONS

Before we discuss the shielding effectiveness observed during testing of many material samples, it is beneficial to verify some additional theoretical concepts and their influence on the measurements. The effect on field intensity of a metallic surface in close proximity to a signal source was observed. Also, tests were conducted on a few samples to ascertain the effect on apparent SE of varying test distances. Finally the change in SE occurring when the sample was driven into saturation was investigated. Material evaluations follow, commencing on page 13.

A. Magnetic Field Intensity

The effect of ferrous and nonferrous materials on magnetic field intensity was measured using the test configuration shown in Figure 18. A field intensity of two Oerstedes was established at 1 KHz using the small loop antenna shown in the foreground. The field was first measured with the test sample and chamber moved 20 feet away, using the Hall Effect Sensor described on page 8. The sensor is shown in the figure taped to a five-foot long wooden support. Each test sample was then placed two inches from the antenna and the amount of change in field intensity was measured as shown below:

<u>Sample No.</u>	<u>Material</u>	<u>Thickness (inches)</u>	<u>db Change</u>
1	Copper	.0377	+ 1.5
3	Copper	.0162	+ 1.0
5	Aluminum	.0299	+ 1.0
7	Aluminum	.0149	+ 1.0
21	Aluminum	.0598	+ 1.3
9	Galvanized steel	.0749	- 1.0
11	Galvanized steel	.0478	- 1.0
13	Galvanized steel	.0239	- .6
15	Terne steel	.0239	- .8
17	Terne steel	.0478	- 1.0
19	Hot-rolled steel	.0478	- 1.0
45	Hot-rolled steel	.077	- 1.0
23	Cold-rolled steel	.0897	- .5
25	Cold-rolled steel	.0478	- .5
27	Cold-rolled steel	.0239	- .9

In summary the presence of nonferrous metals in close proximity to magnetic field sources caused a rise of approximately + 1 db or + 11 percent in the field intensity. The presence of ferrous metals caused a - 1 db or - 11 percent change.

B. Magnetic Field Testing at Different Test Distances

It has been previously stated that theoretical magnetic shielding effectiveness of materials depends on the distance between the source antenna and the shield. Measurements conducted on previous studies bear out this fact. Test results shown in Figures 19 and 20 for galvanized steel and copper were performed in the wall test fixture. The measured change is tabulated below for reference.

<u>Frequency (Hertz)</u>	<u>Copper</u>	<u>Steel</u>
100	4 db	0 db
1K	10 db	4 db
10K	8 db	6 db

The difference can be accounted for by a rise in reflection losses as the test distance becomes larger. Test results show that .0239 inch thick galvanized steel almost meets Class I requirements at 12 inches, while at two inches performance is 5 to 10 db low.

It may be desirable to select a base material on the basis of 12 inch testing for the following three reasons:

1. The two inch test distance will cause greater metal thickness and heavier, more expensive enclosures.
2. The standards for performance have been determined on the basis of testing at 12 inches.
3. Sources of interference would not normally be as close as two inches from the enclosure walls.

C. Saturation Effect on Shielding Performance

The effect of changing magnetic field intensity on the shielding performance of the more standard shielding materials (galvanized, terne, hot-rolled, and cold-rolled steel) is demonstrated in Figures 21 through 24. Test results for low-field intensities (.04 Oersteds or 200 milliamperes flowing in the test loop antenna), medium field intensities (.4 Oersted and 2 amperes), and high-field intensities (2 Oersteds and 10 amperes) are shown. The maximum change produced varied from two to four db. From these results it can be concluded that saturation effects are not of major concern in the design of shielded rooms using these materials.

Initial tests of conductivity and permeability on various samples led one to conclude that the permeability and shielding effectiveness of materials varied drastically in changing field intensity conditions. This was really the effects of leakage due to the causes already noted. Later data under more carefully controlled test parameters showed that this was not really the case.

The effect of saturation on .004 inch thick primag 20 is shown in Figure 25. A change in field intensity from .04 Oersteds (200 milliamps) to 2 Oersteds (10 amperes) produced a maximum change of 3 db in shielding effectiveness.

D. Ferrous Metals

The results of testing on ferrous metals are presented in Figures 26 through 30. Approximately 18 gauge material (.0478 inches) will be required to meet Class I performance standards. Approximately .032 inches (20 to 22 gauge) will be required to meet Class II standards.

It is interesting to note that if a material meets Class I magnetic shielding requirements at 1 KHz it will comply at all other frequencies. This occurs because the slope of the requirement line is much less than that inherent in ferrous metals.

A comparison of the inherent shielding of .0478 galvanized, terne, cold-rolled, and hot-rolled steel is made in Figure 27. Galvanized steel offers significant advantages over other metals. Terne steel performed slightly better than cold and hot-rolled steel. This is summarized as follows:

<u>Frequency (Hz)</u>	<u>Advantage (db)</u>
1K	5
2K	7
4K	7
7K	11
10K	14

Figures 31 and 32 show the shielding effectiveness of Primag 90 and 40 materials exposed to a field intensity of 2 Oersteds. Due to the innate slope of these materials, it would require a thickness of approximately .020 inches to meet Class I performance requirements.

E. Nonferrous Metals

Tests on copper and aluminum sheet materials are presented in Figure 33. These materials can be readily used for Class II and III enclosures.

F. Magnetic Shielding Effectiveness of Composites

The shielding effectiveness of foils with galvanized steel are compared to plain galvanized steel in Figure 34. An .006 inch thick copper foil (facing the energy source) on galvanized steel meets Class I performance requirements. Similar data for cold-rolled steel is shown in Figure 35. Galvanized steel was chosen for the composite tests because of its superior performance over other steels. This choice is born out by the results of Figures 34 and 35.

The results shown in Figure 36 demonstrates many options using .001 inch thick aluminum and galvanized steel. None of those shown meet the requirements of Class I enclosures.

Figure 37 illustrates the many options possible using .005 inch thick copper and galvanized steel. All options meet the requirements of Class I enclosures. Measurements at 12 inches exceed those made at two inches by as much as 7 db.

G. Flame-Sprayed Metals

Flame spraying may be defined as a process of spraying molten material onto a previously prepared surface to form a coating. The coating material is melted in a flame and then atomized into a fine spray. The impacting particles flatten, interlock and overlap one another so that they are securely bonded together to form a dense, coherent coating. Because the molten material is accompanied by a blast of air, the object being sprayed is not excessively heated. These materials can be applied by a variety of flame-spray methods, including the older oxyacetylene and oxyhydrogen systems, as well as the newer detonation gun and plasma arc systems.

The oxyacetylene method was chosen because the detonation and plasma techniques require excessively high temperatures and special chambers. They could not be effectively used on large surfaces.

Materials selected for test were sprayed on 14 x 14 x .25 inch thick masonite panels. The panels were prepared by first coating them with Scotch-Grip 1711 rubber adhesive and a thin coating of sprayed zinc. Test materials were then deposited on the panels shown in Figure 38.

The composition of materials selected for test is as follows:

1. Spraysteel 10, a soft steel with a carbon rating of 10.
2. Spraysteel 80, a hard steel with a carbon rating of 80.
3. Spraysteel LS, a low-shrinkage steel
4. Metcoloy #2, a high carbon, high chrome, hard stainless steel.

5. Metcoloy #4, same as above with slightly less chrome and a small amount of molybdenum.
6. Copper, .020"
7. Aluminum, .040"
8. Zinc, .040"

Ferrous materials were sprayed to maximum thickness. Thicker sprays will not adhere. Nonferrous material thicknesses are not so limited and were selected for optimum performance.

The results of H-field testing are presented in Figure 39. It appears that nonferrous samples (copper - zinc - and aluminum) will all be acceptable for use as Class III enclosures. The results for flame-sprayed copper very nearly match those for a solid copper material of the same thickness. Ferrous materials performed poorly because of their inherently low conductivity and badly degraded permeability due to the spraying process. It is possible that annealing of ferrous samples might restore some permeability, although the procedure appears impractical for use on large walls. The nonferrous materials should be subjected to electric field testing because the porous nature of materials may produce leakage.

Shielding effectiveness for incident E-fields was very good. Between 100 Hz and 100 KHz, these samples exceeded the dynamic range of instrumentation at many points. Measured levels exceeded 140 db in some cases.

The following table shows the class limits for which each material is acceptable.

<u>Sample</u>	<u>Flame Sprayed Material</u>	<u>Class</u>			<u>Figure No.</u>
		<u>I</u>	<u>II</u>	<u>III</u>	
46	Copper (.020")	E	E	E/H	45, 39
47	Aluminum (.040")	E	E	E/H	45, 39
48	Zinc (.040")	E	E	E/H	45, 39
49	Spraysteel LS (.034")	E	E	E/H	45, 39
50	Spraysteel 80 (.050")	E	E	E/H	45, 39
51	Spraysteel 10 (.024")	E	E	E/H	45, 39
52	Metcoloy #2 (.020")	E	E	E/H	45, 39
53	Metcoloy #4 (.060")	E	E	E/H	45, 39

E = acceptable for E-field, plane wave, and microwave shielding

H = acceptable for magnetic field shielding

H. Screen Materials

Performance of most screen materials was not acceptable for any of the class limits established. Monel wire cloth, however, was found to be within 2 - 4 db of the Class I E-field limit (from 100 Hz to 100 MHz), and the Class III microwave limits as shown in Figure 40.

The data shown in Figure 41 shows that none of the screens will meet the requirements for magnetic shielding for any of the three classes of enclosures.

I. Woven Cloth Shielding

Several woven or cloth-type shielding materials were tested for shielding effectiveness. None of the samples met the requirements of either Class I, II or III enclosures. Figure 42 shows that they were effective for incident electric fields from 100 Hz to 100 KHz. However, Figure 41 illustrates that the class of materials fails to meet the requirements for magnetic shielding effectiveness.

J. Metallized Kapton Foils

Four types of metallic foils using a Kapton base were evaluated for shielding effectiveness. All four samples performed very well. The shielding effectivity exceeded the dynamic range of instrumentation from 100 Hz to over 100 MHz. All requirements for Classes I and III were met, as shown in the table below. Class II electric field limits were not met between 100 KHz and 30 MHz, except for sample 42, 70 and 71.

<u>Sample</u>	<u>Material</u>	<u>I</u>	<u>II</u>	<u>III</u>	<u>Figure No.</u>
41	Kapton +3 mil cu	E		E	43
42	Kapton +3 mil cu & 3 mil Fe/Ni	E	E	E	43
70	Kapton +.4 mil cu	E	E	E	44
71	Kapton +1.2 mil Fe/Ni	E	E	E	44

Another foil tested was .006" aluminum foil. It proved to be effective for Class II and III limits for magnetic fields.

K. Air-Inflatable Shields

These materials failed to meet any of the requirements for Class I, II or III enclosures. Two samples (63 and 64), however, were effective for Class I enclosures, up to 100 MHz. Figure 42 contains the results of the evaluation.

5. SIMULATED SEAM TESTING

A. Construction of Simulated Permanent Seam Configuration

Sixteen configurations using 20 gage galvanized steel have been constructed for evaluation of permanent seams in the laboratory fixture. These configurations are listed in Figure 48. Two fundamental configurations are the basis of this study. One configuration simulates the butting together of two flat sheets by cutting a 1/16 inch wide by 9 inch long slot in a plate and covering it by the following alternative techniques:

1. Solder
2. Copper Tape
3. Zinc Flame Spray
4. Copper Flame Spray
5. TIG Weld
6. MIG Weld
7. Silver Solder

A second alternative is to overlap two sheets by one inch and use the same sealing techniques on both sides of the overlap.

B. Magnetic Shielding Effectiveness of Simulated Seams for Permanent Enclosures

The magnetic shielding effectiveness of the simulated overlap and butt seam closures using the above described types of joints, is shown in Figures 49 through 52. Three of the simulated overlap seams fail to meet the magnetic field requirement of the required conceptual design. These are the TIG welded, copper taped and silver soldered seams. However, the magnitudes of the failure for the TIG and silver soldered closures is less than the systematic error inherent in these tests. With further testing it would appear probable that these closures would also meet the magnetic requirements of the required conceptual design. The shielding effectiveness for the butt seam closures indicates that only the copper and zinc flame sprays are adequate closures to meet the magnetic requirements of a Class I enclosure. With further testing however, the MIG or TIG welded butt seam might also prove to be adequate closures required of the conceptual design.

C. Application Note

It is of interest to note that although galvanized steel was selected as the simulated wall material on the basis of its overall superior performance, many difficulties arise when attempting to close the seam by most of the techniques considered, due to the galvanization. When TIG or MIG welding and silver soldering galvanized steel, a fine powder is formed at the surface, contaminating the metallic nature of the closure with non-metallic voids of powder. These often take the form of pin-holes through the closure causing the seam to leak. Furthermore, during the formation of this powder a dense toxic gas is given off causing difficulty for, and endangering the lives of, personnel performing such closures.

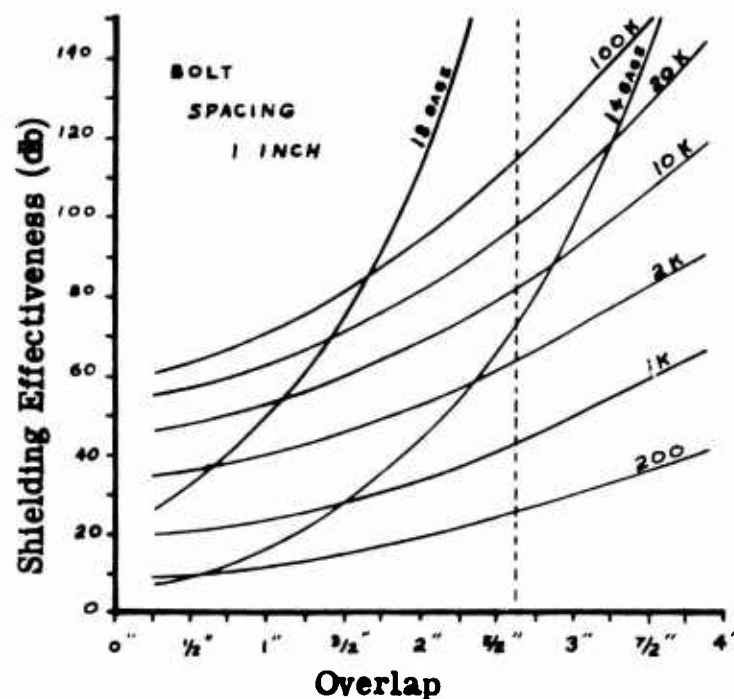
When attempting to flame spray a closure, the seam must first be roughened and cleaned, then primed with a copper flame spray undercoat, and then sprayed with the closure material (which may be copper itself). The zinc and aluminum flame sprays do not adhere to galvanized steel but will adhere to the copper flame spray undercoat. It is also of interest to note that of all the closure processes involving heat, the flame spray process appears to cause the least warping of the metal.

In conclusion it would appear from test results that the copper and zinc flame sprays are adequate closures of either a butt or overlap seam to meet the Class I enclosure requirements. Although further testing of welded seams could perhaps show sufficient improvements to meet Class I requirements, the hazards and difficulties involved in using galvanized steel still remain as a significant disadvantage. However, if terne hot or cold-rolled steel were employed as the wall material, welding would have significant advantages over flame sprays from the standpoint of ease of application and cost.

D. Seam Overlap Criteria

The following is a proposed procedure for determining the amount of seam overlap required to prevent leakage from portable shielded rooms.

1. Select a metal type and material thickness to be used.
2. Establish a seam configuration and sealing technique (such as bolt spacing).
3. The amount of overlap to be tested (.5, 1, 2, 3, 4 inches).
4. Test each configuration for magnetic shielding effectiveness over the low frequency range.



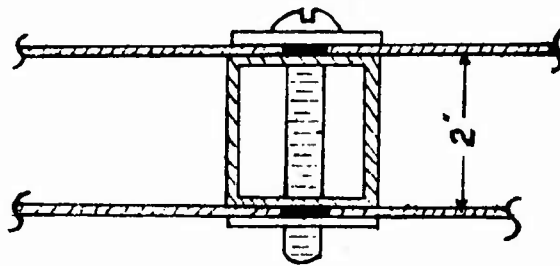
5. Plot a graph of the shielding effectiveness versus inches of overlap for a fixed bolt spacing as shown above. One graph will be obtained for each bolt spacing.
6. Determine the optimum overlap by locating the measured magnetic shielding effectiveness of the metal sheet on each frequency line. A curve will be formed which becomes asymptotic to some amount of overlap, as shown by the dotted vertical line. Different curves will be obtained for each metal thickness.

E. Magnetic Shielding Effectiveness of Simulated Seams for Portable Enclosures (bolt-together)

Tests were conducted in the cylindrical test fixture to determine the effects of overlap on the magnetic shielding effectiveness of seams. The configurations tested are described and listed in Figure 53. Two fundamental configurations were tested for overlap variations; an overlap seam with a simulated metal structure plate and an overlap seam without a simulated structure plate. As can be seen from the test results shown in Figures 54 and 55 none of the overlap configurations meet Class I performance requirements. However, all of the overlap seam configurations meet Class III requirements. Only the two inch overlaps will meet the Class II performance requirements.

A third fundamental configuration, a simulated wood structure, was tested in an attempt to study the effects of the simulated support structure on the magnetic shielding effectiveness. In Figure 56, the test results are compared for each of the configurations considered. It may be reasonable to assume that the slightly better performance of the wood structure is due to its ability to apply more uniform pressure on the wall seam. This forces the wall seam and the overlap plate to be in more uniform contact.

On the basis of the above results, little can be concluded with regards to establishing criteria for the choice of overlap. This is particularly evident when consideration is given to the change in shielding effectiveness resulting from variations of the effective material thickness for each overlap. Thus, further testing was conducted to determine if similar results could be obtained at distances greater than the two inch test distance employed for the above test. One set of tests was conducted in the cylindrical test fixture on a simulated seam (S/N 97) with 1.5" loops. Another set of tests was conducted on an actual enclosure with seams as shown below.



The enclosure seam tested was a 1/2" overlap seam and equivalent to two simulated 1/2" overlap seams (S/N 97) placed two inches apart. The enclosure test was run with 12 inch loops. The results of testing are presented in Figure 57. It is evident from these results that the test distance has significant effects on the measured shielding effectiveness.

Test results indicate, however, that only the loop to loop distance is significant and the loop to sample distance has only small effects. It is interesting to note the significant increase in magnetic shielding effectiveness for the test run on the actual wall seam as compared to test results in the cylindrical fixture. Since the wall seam is in a double wall enclosure, this would indicate, to some extent, the effect of applying the simulated seam data to double wall enclosures.

6. IN-SITU ENCLOSURE EVALUATIONS

A maximum amount of information regarding potential sources of leakage in commercial enclosures can be obtained by surveying existing enclosure installations. The intent of this testing was to determine the state-of-the-art in low leakage design. Areas investigated were door seams and handles, air vents, corner and wall seams, and filter panels.

A. E-Field Testing

Test samples were subjected to electric fields at various frequencies by a procedure adapted from the shielding effectiveness tests described in part B of section II of this report. Rod, dipole or horn antennas of the type in current usage for RFI measurements were employed as transmitting and receiving antennas.

In the 14 KHz to 30 MHz portion of the spectrum, a 1/2 meter vertical rod antenna was used for both signal source and pickup device. Calibration of the test setup was accomplished in the following manner.

The antennas were placed in a vertical position, outside the enclosure 24 inches plus the wall thickness apart. Signal generator and receiver attenuators were adjusted for maximum dynamic range and a reference level established. Measurement of the shielding effectiveness of the sample was then accomplished by moving the receiver antenna inside the enclosure and noting the signal level. The difference between this level and the reference level is the SE of the sample.

B. Plane Wave and Microwave Testing

Planewave and microwave testing was accomplished in a similar fashion. However, certain precautions were necessary to insure the validity of the measurements. Calibration of the test setup was again accomplished outside the enclosure, using tuned dipole or horn antennas.

A minimum separation of two wavelengths was established between the test sample and the transmitting antenna, and antenna orientation adjusted to provide maximum field intensity on the sample. The receiving antenna was then located between 2 and 8 inches from the test sample and oriented for maximum indication on the RI-FI meter. Care was taken to minimize the effect of reflections and prevent capacity coupling.

A reference level was established under these conditions, after adjusting the signal generator and receiver antennas for maximum dynamic range. The receiver antenna was then relocated inside the enclosure and the signal level observed.

providing a SE figure for the enclosure. During these tests, the area inside the enclosure was scanned to locate the point of maximum leakage. A two inch or greater separation between the receiving antenna and the enclosure wall was maintained to prevent capacity coupling.

C. In-Situ Testing of Seams and Access Configurations

Figure 58 describes the scope of tests conducted on several existing enclosures, seams, and access configurations. The facilities tested were grouped into two classifications to further evaluate seam and access openings. New enclosures were tested to insure that attenuation met the requirements of the manufacture. Older facilities were tested to determine degradation of shielding due to use, and also to determine the effect of dis-assembly and relocation upon the attenuation. Test data obtained during these investigations will be found in Figures 60 through 77 while Figure 59 shows the seam types tested.

One commercial enclosure tested was similar to the one proposed in Figure 78 a and b. The type of seam and door closure used in this shelter are pictured in Figure 79. Type 8 would apply to Figure 78b and type 9 to Figure 79a. Test results will be found in Figures 80 - 87.

SECTION III

CONCEPTUAL ENCLOSURE DESIGN

1. BASIC DESIGN CRITERIA

A. Enclosure Materials

A design concept for either permanent or portable enclosure must center around the type and thickness of metal required to provide the required amount of shielding effectiveness. Where magnetic field shielding is required, thicker ferrous materials are usually employed. For high levels of electrical field shielding effectiveness, thin solid metal sheet is primarily recommended; i.e., steel for E-field and H-field shielding and aluminum for E-field shielding only. Other materials such as screen, wire cloth, metal impregnated cloth, spray coatings and foils are used where low to moderate levels of E-field shielding effectiveness are required. However, in many instances, the structural requirements of an enclosure are the predominate factors in the determination of enclosure material type and thickness.

B. Enclosure Seam Design

The final configuration of a shielded enclosure must address itself to three essential principles of seam design.

1. The total length of seams should be minimized to reduce potential sources of leakage and to reduce the time and cost of erection. In both permanent and portable applications the sealing of seams requires much time and expense, in addition to causing long term maintenance problems.
2. The location of seams should be away from points of maximum stress, such as edges. Since these points will be subjected to movement under strain, seams will more readily leak over long periods of time.
3. Butting seams should meet in the same plane. Sealing in two or three planes becomes extremely difficult and leakage problems are severe.

Three other parameters become of prime importance in maintaining shielding integrity for portable enclosure seam configurations which do not use gasket materials and are subjected to incident fields at frequencies above 200 MHz (E-field) and below 1 MHz (H-field).

These are: the length of the seam cross-sectional leakage path (or seam width), the seam clamping pressure, and the flatness of metals in the seam. This is analogous to maintaining a continuous weld, for permanent enclosure seams, with minimal impurities and without breaks or pin-holes. Specific recommendations, however, for clamping pressure and leakage path length can only be made upon definition of the structural requirements of the seams, the desired level of shielding effectiveness and the enclosure material. In general, using RF shielding gaskets in portable enclosure seams is not recommended for the above frequency regions, particularly where magnetic field shielding is required.

Various enclosure penetrations, such as for filter leads and honeycomb air vents, can normally be considered as seams and the above criteria employed. However, in many instances where the effective seam length is small, particularly for moderate shielding effectiveness requirement, gasket materials may become feasible.

A conventional commercial enclosure, made from 4' x 10' and 4' x 8' panels, is shown in Figure 78a. All of the above principles are violated in this configuration. The total length of seams is 1072 feet. Seams are located at all edges and corners and three plane seams are required at each of the eight corners.

Figure 78b shows the same enclosure configuration with vastly improved characteristics. Both end sections are continuously welded one foot around the corners into a shoe box top configuration, so that there are no three plane corner seams. Roof and floor panels are 6 feet wide by ten feet long and are bent around corners to avoid the two plane seam. Six by six panels are used along the length of walls and require one plane seams. The use of larger panels and welded end sections reduced the linear seam length by one-half, to 536 feet. An added advantage is that end sections can be joined to form a packing case for the enclosure. All of the above principles have been observed to provide a great reduction of potential leakage points and a large potential reduction of erection - disassembly time which will result in a substantial cost reduction.

Figure 78c offers the option of reduced ceiling space which reduces the linear seam length by another 20% to 432 feet. However, where a clear wall height is specifically required, this option is not recommended. End sections are welded around corners, and the floor is identical to Figure 78b. The curved roof eliminates two plane wall seams, and requires the use of 6' x 12' panels. From a shielding standpoint option C appears to offer the best performance, at the cost of mostly unusable ceiling space. This configuration also would allow for using end sections as packing cases while concurrently reducing the total structure weight due to the reduced volume enclosed.

C. Structural and Environmental Requirements

A design concept must in addition to shielding, be responsive to structural and environmental factors. In general, shielded enclosures are employed in protected areas and are not subject to extreme temperature variations, wind, and moisture. However, when an enclosure is subject to these climatic conditions, many additional factors must be considered.

Particular attention must be given to moisture proofing of seams from the various forms of precipitation. Paint and dirt must also be kept out of the seams. Corrosion and oxidation of seam materials must be kept to a minimum.

Temperature variations can cause significant stresses to occur in joint members, fasteners, and structure panels, particularly where fabrication tolerances are important.

Structural requirements for an enclosure tend to be somewhat in opposition to maintaining shielding integrity. The more severe the structural requirements become for roof loads, floor loads, wind loads, etc., of an enclosure, the more difficult becomes the task of maintaining RF shielding integrity. Cost and weight are also significantly increased as structural requirements become more severe.

The specifications for shielded enclosure design under this contract included structural and environmental parameters, as well as limits for attenuation levels. The more important of these structural requirements will be discussed briefly below.

(1) Dimensions: Portable shelters shall have a 16' x 32' floor plan. Permanent shelters shall have a 40' x 100' floor plan. Both enclosures must have a clear wall height of at least 10'.

(2) Roof: The enclosure roofs shall have a slope of 1/4" in 1' or greater.

(3) Loading: Each enclosure will be subjected to the following loads:

100 mph	wind load
25 psf	dead load, roof
25 psf	live load, roof
150 psf	live load, floor

(4) Weight: The portable shelter shall have, as a design goal, a shipping weight of 6000 lbs.

(5) Volume: The portable shelter shall have as a design goal, a shipping volume of 500 cu. ft.

Detailed discussions of the structural requirements will be found in later portions of this section, and also in Appendix III Section C.

2. EVALUATION OF TEST DATA RELATIVE TO ENCLOSURE DESIGN

A. Evaluation of Test Results of Shielding Materials

The results of shielding effectiveness tests on various materials are presented in Figures 26 thru 46. A summary of the material types and minimum thickness conforming to the specified requirements for each classification of enclosure are listed in Figure 14. The thickness of each material is a minimum requirement and may have to be increased in order to meet structural requirements. If the thickness is increased, the attenuation capabilities (excluding seam leakage problems) of the enclosure for incident magnetic fields (at very low frequencies) would increase proportionately.

B. Evaluation of Seam and Door Test Data

A summary of test results for permanent enclosure seams, as they conform to the three shielding classifications, is presented in Figure 15. The results of testing on the various types of portable enclosure seams presented in Figure 59, are similarly presented in Figure 16. A summary of tests on typical door seams is also presented in Figure 16. It is apparent from the in-situ seam and door tests, that considerable degradation occurs to these various seams over a period of time. Thus, particular attention was given to these effects in formulating a conceptual design.

C. Compatibility of Shielding Limits with Test Results

The slope of Class I limits (the change in shielding effectiveness vs. frequency) was chosen to be a straight line changing at a rate of approximately 35 db per decade between 1 KHz and 100 KHz. While this slope appears to nearly match that inherent in nonferrous metals (reference Figure 39), it is quite different from that inherent in the ferrous materials required to provide this level of shielding (reference Figure 27). While ferrous shielding performance far exceeds the implied limits at 300 Hz (by 13 db) and 20 KHz (by 25 db), it barely complies with requirements at 1 KHz (by 3.5 db). A change in the slope of the limits to more nearly match that of the ferrous materials required to meet these limits would reduce required material thickness and hence the cost and weight of enclosures. The flatness of all requirements above 4 KHz has been well chosen to limit magnetic field leakage through seams and access openings. Class I, II, and III requirements are listed in numerical order according to the difficulty of compliance (Class I requiring thicker materials, more expensive, heavier, more difficult to maintain, etc.).

The limits for electric field performance are not consistent with within themselves, nor with the magnetic field limits. These limits imply that the difficulty of compliance (hence cost, weight, etc.) are Class III, Class II, and Class I in that order. A more practical set of limits would be to reduce Class II and III limits to a level at or below those for Class I enclosures.

In addition to the required shielding effectiveness of 140 db (a reduction factor of 10^7) is beyond the dynamic range of measurement of the vast majority of instrumentation and certainly beyond that required by MIL-STD-285.

Finally the slope-off in Class I limits from 100 db to 70 db between 10 KHz and 1 KHz, while typical of magnetic field performance, is not found in electric field testing. Examples are shown in Figures 40 through 46 where even screen performance is inherently high at low frequencies. A more consistent limit would increase to 120 db for Class I enclosures below 10 KHz.

The plane and microwave limits appear to be self consistent and agree with the magnetic field limits with the possible exception that Class I and II limits are identical. This implies that better (more costly and difficult to maintain) seams are needed to prevent leakage from degrading performance. Class I seams must be equivalent to Class II seams; Class III seams being the least demanding.

Plane and microwave limits for Class I and II enclosures can be met by using the highest quality seam configurations to prevent leakage. Class III limits are significantly easier to meet.

While magnetic field and plane wave-microwave limits appear nearly self-consistent, the apparent lack of self-consistency in the electric-field limits suggest possible revision. A suggested self-consistent set of limits is presented in Figure 47.

3. PORTABLE ENCLOSURE DESIGN

A. General

A survey of structure manufactures and their products was conducted to determine if any enclosure currently manufactured (in either its existing configuration or a modified version) would conform to the structural and shielding requirements specified for the three classes of portable enclosures.

The following paragraphs discuss promising options which were considered during the program, but were not selected because of significant technical limitations.

The feasibility of loading phenolic structures with shielding materials to provide portable shielding enclosures with the required weight, strength, and shielding characteristics was considered. Woven Structures, Inc. has presently developed a portable shelter fabricated of fiberglass cloth, impregnated in epoxy resin which encloses rigid, self-extinguishing polyurethane foam. The impregnated material can also be of woven metallic threads and made elastic for inflatable structures. These structures have demonstrated exceptional strength and heat retention characteristics. However, from the results of magnetic field tests on woven metallic fabrics, the magnetic shielding effectiveness of these materials is insufficient to conform to the specified requirements for the three classes of portable enclosure. Further consideration was given to metalized mylar and metalized nylon with similar results.

Insulated wall panel "Temp-Con" consisting of a rigid urethane core material foamed between two sheets of steel are manufactured by Soule Buildings Division of Soule Steel in San Francisco, California. If an RF seam configuration could be adapted to these panels, a low cost, high strength, double wall 26 gage galvanized steel structure could be constructed with a minimum of erection time. However, upon investigation of the feasibility for adapting RF seams, etc., the following disadvantages were determined sufficient to prohibit use of these panels.

- (1) Channels in surface will be very difficult to seal against RF leakage.
- (2) Welding processes for seams will melt polyurethane filler material.
- (3) Seams would have to be cleaned for RF sealing.
- (4) The standard forty-two inch widths available would produce considerably more seams than larger, more desirable widths.

(5) Corner and roof to wall seams would be difficult to seal.

(6) Conventional, maximum seal length room configurations would be necessary.

Wonder Trussless Buildings feature modular, double corrugated, arch steel panels that bolt together to form a completely self supporting structure. No trusses or frames are required, regardless of span width. Their buildings have excellent fire retardant characteristics and high strength. However, the corrugated nature and small span width of the arched panels make RF sealing impractical and thus these structures as they presently exist, appear unadaptable to shielding applications.

Zero Manufacturing has produced a number of permanent shielded structures that can be moved intact. Their basic technique is to use a double walled, honeycomb filled panel and riveted seams with inside and outside angle closures. Although simple in nature these seams would probably leak RF energy due to the difficulty in maintaining the flatness tolerances in the corner angles. Zero has not qualified a structure to meet the shielding levels specified for this conceptual design.

Inland Steel Corp. manufactures roofing systems which may be adaptable to shielding requirements. Type NF deck offers high strength properties with an overlap hooking seam that could be sealed against RF leakage. The flat inner panels could be sealed at seam interfaces. Principal disadvantages appear to be seam configuration that is not ideal and panel widths that are restricted to two feet.

Lindsay Structure Division of International Steel Co. manufacture a type of structure which utilized the conventional right rectangular parallelepiped configuration. Without regard to total seam length or location at maximum stress points the advantages appear to be:

- (1) Excellent seam shielding characteristics.
- (2) Simple quick erection with semi-skilled workers.
- (3) Simple tools are required for assembly.
- (4) Maximum strength with minimum panel thickness.
- (5) Low cost.
- (6) Galvanealed panels offer good weather protection.

Major disadvantages are:

- (1) While this technique is ideal for small rooms (to 10' roof spans) it appears to require a great deal of trussing for larger roof spans. The existing configuration does not comply with our structural requirements.
- (2) Lindsay appears to be limited by a contract agreement to sell all shielded structures through one retailer.
- (3) There are no provisions for isolation from heat, cold, moisture, etc.

B. Class I and II Conceptual Enclosure Design

The proposed concept for the Class I and II enclosure shown in drawings A100 thru A117 of Appendix III is a result of evaluations of material tests, seam tests, structural analysis and state-of-the-art fabrication techniques. This concept has numerous advantages when compared to existing commercially available portable enclosures. Many of these advantages are apparent when reviewing the drawings, but several are not readily identifiable. From a shielding viewpoint this concept has the most securely clamped and longest overlap leakage paths of any commercially available shielded enclosure. Each fastener is capable of delivering approximately 4000 lbs of clamping pressure giving rise to an overall seam closure pressure of approximately 1000 lbs/in². This solves the problem of providing low reluctance paths to prevent flux leakage from degrading magnetic field shielding. Furthermore, it may be noted that there are no three (3) plane joints. By using prefabricated edge pieces which use end castings as the corner pieces, the seam configuration runs continuously around a corner and actually intersects only identical seams at right angles in the same plane.

In addition to maintaining a tight seam with a long leakage path over the seam width it is desirable to minimize the overall seam length, since seam length and shielding effectiveness can be directly related. This has been accomplished by using large lightweight paper honeycomb core sandwich panels. Structurally, the use of these panels combined with the tightly clamped and rigid edge configuration negates any use of internal or external structural columns or beams to satisfy loading requirements. This enhances a rapid assembly and gives rise to an extremely clean shell type enclosure.

Thus all components function both structurally and for RF shielding and there are no superfluous structural members protruding internally or externally which might give rise to excessive weight, cost and inconvenience. It should be noted further that with the existing design, all components are interchangeable.

The overall estimated weight (including packing and shipping container) of the Class I steel option enclosure is 24,000 lbs. The Class I aluminum option and the Class II are both estimated at 7,000 lbs. The shipping volume is estimated for both Class I options and the Class II enclosure at 490 cu. ft.

The use of a false roof, as shown in A100 and A101, provides the required 1/4 in/ft roof slope without necessitating a complex non-orthogonal seam design which would tend to be costly, unreliable, and difficult to maintain from a shielding standpoint. In addition, the false roof provides a protective covering for any external equipment which may be required on the roof of the enclosure and protection for all roof seams from residual water, reducing roof seam water tightness requirements to a minimum.

The raised floor framing is employed for leveling, weather protection, and floor seam inspection. Siding skirts are provided to reduce wind lift and the erosion of the foundation.

Initial design criteria discussed above specified that two doors were desirable; one for personnel access (measuring 3' x 5'8") and a separate full size equipment hatch (measuring 6' x 6'8"). The concept of two doors is undesirable because doors are the most difficult location to obtain and maintain RFI shielding integrity. In addition the cost of two doors is unnecessary. A double width door, 6' x 6'8", meeting the prescribed shielding requirements can be obtained commercially at a reasonable price. For personnel entry only one half of the door need be used. This approach should prove desirable because it saves cost and weight, in addition to enhancing the shielding quality and long term reliability.

Facilities for grounding the outside wall of the enclosure to an earth ground at each corner of the structure is provided as shown in Drawing A100. Additional grounding can be provided at each of the jacks with a ground rod attached to the jack base plates. Grounding is provided thru attachment of these rods to an appropriate grounding grid. A specific grounding technique, however, can only be defined upon definition of such factors as the water table, type of soil and terrain. These grounding stakes also provide anchoring for the enclosure to the terrain, in order to prevent movement under wind loading.

Attach points for maps, charts, or lighting must not penetrate the skins of the sandwich panels in order to maintain the

shielding integrity of the enclosure. Small pads can be epoxied to the enclosure wall to provide an attachment point, and then cut off during disassembly and replaced.

In order to prevent oxidation and corrosion, all surfaces of the respective materials are treated with anti-corrosive agents. For the aluminum options, the surfaces are cleaned, deoxidized and treated with Oakite conductive Chromi-Coat L-25 before painting. This process can also be applied in the field when repairs or scratches require treatment. For the steel option, the surfaces are either galvanized or zinc plated prior to painting.

Temperature requirements were not specified in the above design criteria and have not been specifically considered. However, due to the tolerances specified for the existing concept and the insulated nature of the honeycomb panel skins, temperature variations can have a marked effect upon the feasibility of this concept. One solution to this potential problem with respect to fastener hole locations, would be to modify the fixed fastener insert to a floating insert. This would allow some deviation in fastener hole alignment and since the insert hole could be made blind, no deterioration to shielding integrity would occur. Depending upon further definition of anticipated temperature gradients (internal to external) across the sandwich panels, core fractures and panel bending should be considered in future evaluations.

The erection procedure for the Class I and II portable enclosure options is briefly described below:

- (1) Clear terrain, prepare trench for skirts and construct anchoring and ground system.
- (2) Assemble raised floor framing.
- (3) Assemble floor panels, center extrusion and all peripheral floor edge extrusions.
- (4) Place each of the wall panels in the 20' floor edge extrusion, successively assembling the 10' wall seam edge extrusion at corners. The last extrusion must be slid down seam from the top.
- (5) Assemble roof as flat plate with center extrusion and 20' edge extrusion attached.
- (6) Place assembled roof system on structure.
- (7) Assemble roof struts and roof frame stay on roof.
- (8) Place cover fabric on struts and securing all tie points.

- (9) Mount shielded room door in its appropriate panel.
- (10) Mount power line and signal line filter panels.
- (11) Attach grounding and anchoring system.
- (12) Lay or apply flooring.
- (13) Test enclosure for RF shielding integrity.

Special care must be given to maintaining clean and undamaged seams (edge extrusions); free from dirt, paint or any foreign material. Particular attention must be given to proper insulation of fasteners. They must be fully inserted before expanding in order to insure proper seam clamping pressure.

Although a minimum number of special tools are required for assembly and disassembly of the enclosure, a lifting hoist will be required to lift the wall panels and roof in place. Removable lifting lugs (not shown on drawings) are located at each corner of the sandwich panels. A special alignment tool is required to bring floor and roof panels into alignment prior to securing with the center extrusion. A standard set of wrenches is all that is required for the installation of fasteners. Thus, with the use of quick connect-disconnect fasteners and a minimum number of enclosure components, the estimated erection time for both classes of enclosure is estimated at 60 man hours on the basis of a six man crew.

Two methods are available for repair of the enclosure in the field. In the event that major damage occurs to a panel, it must be replaced. All components, except the two specialized wall panels, are interchangeable.

Only a minimum number of replacement components need be kept in reserve. When minor damage such as small punctures in the sandwich panel skins occur, a repair kit is required which contains small aluminum or steel patches, a hard setting core filler, foam epoxy, Oakite ChromiCoat and an RF shielding epoxy. For punctures less than approximately one half inch in diameter the surface should be stripped to bare metal, treated with Oakite ChromiCoat, and then filled with the RF shielding epoxy. Punctures in the skins greater than one half inch in diameter or equivalent require a metal patch. The damaged core region should be filled with the hard setting core foam epoxy. The skins should be cleaned and treated with Oakite ChromiCoat. Then a metal patch is epoxied over the area with a minimum 3 inches of overlap on all sides of the hole. The patch is taped with aluminum or copper tape during and after the curing of the epoxy. The skins are then repainted.

C. Class III Conceptual Enclosure Design

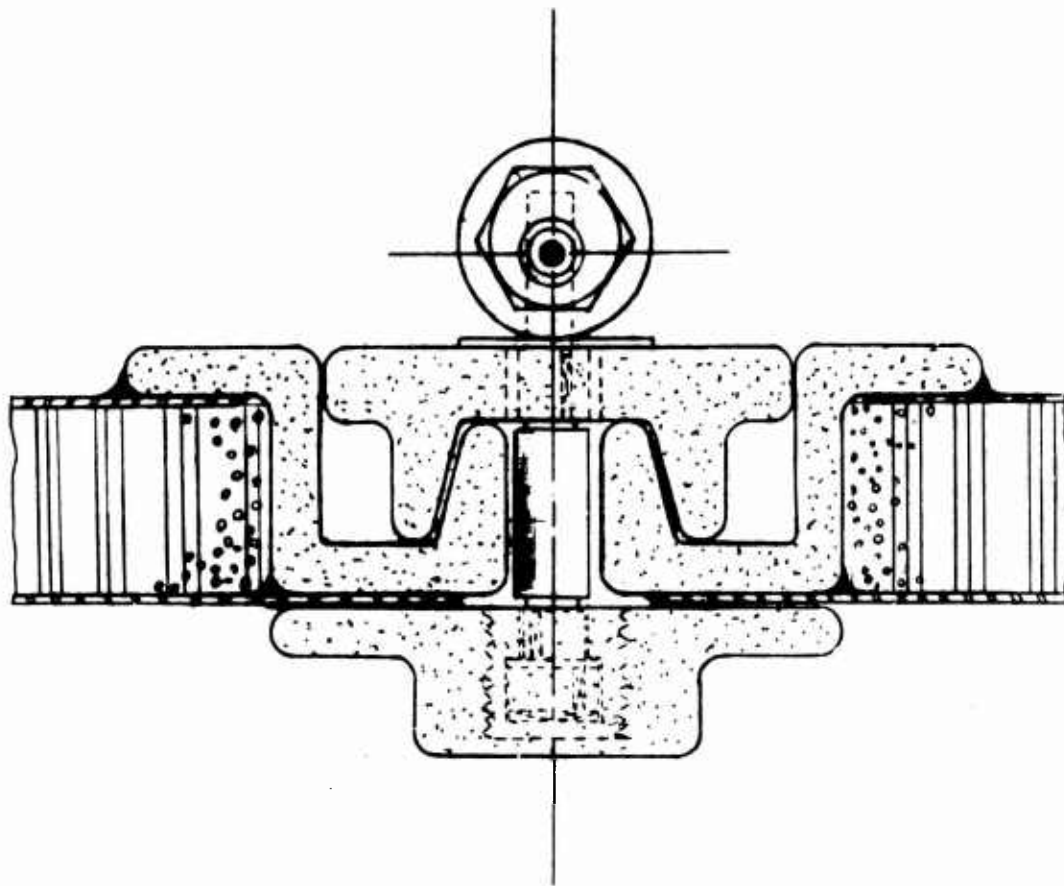
The proposed concept for the Class III portable enclosure is shown in drawings A118 thru A127 of Appendix III. The reduced requirements for this class of enclosure allow for a conceptual design less dependant upon seam criteria than the Class I or Class II design. However, since a rapid enclosure assembly and disassembly time is also required for the Class III enclosure, a seam fastening concept similar to the Class I and II design is necessary. With the relaxed seam criteria, a greater overall length of seam can be tolerated, allowing small (10' x 7.5') light weight sandwich panels to be used rather than the large 10' x 20' panels used in the Class I and II design. This would seem to make the Class III enclosure somewhat more practical than the Class I and II enclosures, since assembly and disassembly procedures do not require the use of a hoist.

As in the Class I and II conceptual design, the wall panels function as a continuous column and side and end-wall columns are not required. However, due to the increased size of this enclosure and the greater number of panels comprising the roof and floor, structural roof and floor beams are required. As in the Class I and II conceptual designs a complex non-orthogonal seam design is undesirable and a false roof is used to provide the required 1/4 in/ft roof slope. As a result, the light weight roof box beam functions as a structural roof beam, a framing member for the false roof and a seam closure for shielding and weather proofing. Similarly the light weight floor box beam serves as a structural floor beam and a seam closure.

Prefabricated light weight welded end-sections are used to simplify the assembly and provide a seam concept void of three-plane seams. However, two plane seams are inherent in the Class III design. All panels and end-sections are interchangeable with the exception of the door end-section and any one panel can be removed independently. Thus, only a single 3'0" x 6'8" door is required, since a wall panel will suffice for an equipment hatch.

The grounding, attachment, and repair procedures and techniques for the Class III conceptual design are identical with the Class I and II design. Similarly, ChromiCoat L-25 is applied to all surfaces to prevent oxidation and corrosion.

An alternate to the basic joint concept shown in drawing A119, which allows for slightly better shielding effectiveness by virtue of using the load forces to increase the joint clamp-up pressure is shown below. However, with this option the fasteners may become an undesirable protrusion into the clear space of the enclosure. This option can be easily incorporated into all joint details in the Class III enclosure if desired.



The erection procedure for the Class III portable enclosure is briefly described below:

- (1) Clear terrain, prepare trench for skirts and construct anchoring and grounding system.
- (2) Assemble raised floor framing.
- (3) Assemble floor panels with floor beams and edge joint extrusion.
- (4) Position one end-section and its adjoining wall panel and secure with fasteners.
- (5) Repeat step 4 for remaining three (3) end sections.
- (6) Install and secure all appropriate adjoining seams for the remaining wall panels and center end-section seam.
- (7) Position roof beams - do not secure.
- (8) Position the roof panel adjoining an end-section and secure at end-section and edge joint extrusion. (Brace or temporarily fasten the interior corner of panel).

- (9) Repeat step 8 for opposite end section.
- (10) Position center roof panel and secure to edge joint extrusion and roof beams.
- (11) Repeat steps 8, 9, and 10 for other side of structure.
- (12) Secure all remaining seams and install roof cover fabric.
- (13) Mount power line and signal line filters.
- (14) Attach grounding system.
- (15) Lay or apply flooring.
- (16) Test enclosure shielding integrity.

As in the Class I and II erection procedure, particular care must be taken to maintaining clear and undamaged seams. The estimated erection time for this design is 80 manhours (based on a six man crew). The shipping volume and weight for the Class III enclosure is 490 cu ft and 9,500 lbs respectively.

4. PERMANENT ENCLOSURES

A. Class I and II Conceptual Design

Based on material and seam evaluations (see Figures 14 and 15), a steel enclosure with either MIG welded or flame sprayed seams conforms to the Class I enclosures requirements. Similarly, aluminum, copper, or steel with soldered (tin or silver), flame sprayed (copper or zinc), or welded (MIG or TIG) seams conforms to the Class II enclosure requirements. Of the above mentioned seam closure techniques, welding appears to be the most feasible. Overhead and vertical wall seams are very difficult to solder. Furthermore tin solder has limited structural strength. Flame sprayed seams are costly and structurally unreliable; they tend to be brittle and crack easily. A uniform thickness of flame spray is also difficult to maintain during application. Welded seams are structurally reliable and, with proper quality control MIG welded seams are capable of maintaining high levels of shielding effectiveness. Thus, from considerations of cost, weldability, and shielding effectiveness a welded steel enclosure is recommended for both Class I and Class II requirements. Although the Class II enclosure design requires less material thickness than for Class I, the seam requirements are almost identical. Thus, considering minimum material thickness welding for and structural requirements, welded 16 ga. (.060") steel panels are recommended for both Class I and II permanent Shielded Enclosures. The proposed concept is shown in Drawing B100, B101 and B102. Commercially available from such manufacturers as Electromagnetics Incorporated in Los Angeles, the proposed concept represents standard commercial design in welded steel shielding structures. This structure is entirely self supporting.

The steel panels are MIG welded to a rigid steel structural frame which acts as a back plate for shielding seams. Structural only welds can be standard arc welds. Typical penetrations such as for air vents and power lines are shown in Drawing B100. The door framing is shown in Detail C of Drawing B101. The estimated erection time is 250 man days.

B. Class III Conceptual Enclosure Design

As shown in Figures 14 to 16 and the material and seam options for this class of enclosure are numerous. The prime factors involved in selecting a material and seam configurations appears to be the structural requirements and whether or not the resulting shielded enclosure is constructed as a self supporting structure, or installed interior to an existing building. A self supporting structure by virtue of its structural requirements and cost considerations, becomes a Class I or II enclosure design. However, using foils (i.e., aluminum, copper, steel) for constructions of a thin wall shielded shell interior to an existing or new building, gives rise to a Class III conceptual

design. Primarily this concept consists of a typical building shell of standard construction and metal foil attached and sealed as shown in Drawing B103 of Appendix IV. The seam configuration shown is an overlapped metal taped seam. Flame spray could be used as an alternate configuration, however, the excessive heat generated during application might require a more fire resistant backing. Although plywood sheeting is shown, alternate backing such as masonite could also be employed.

Penetrations, such as for lighting and air vents should be considered as for Class I and II with the exception that shielding requirements are less and that a taped or flame sprayed seam around the penetration is sufficient. The door, however, should be an RF shielding type and adapted to the building shell with the metal foil permanently intruding into the door seam.

SECTION IV

COST EFFECTIVENESS ANALYSIS

1. GENERAL

Previous sections of this report have described at some length the test and evaluation methods used to evaluate the shielding effectiveness of various materials, discussed the results of many investigations, and explored various enclosure construction methods.

Based upon the results of these evaluations, a series of conceptual designs were formulated that meet the specifications both electrical and structural, for the various classes of enclosures required. These conceptual designs include several unique construction methods that eliminate or minimize deficiencies normally encountered in most existing shielded enclosure designs.

To complete the discussion of the shelter designs previously described, this section of the report will examine the various configurations from a cost aspect. Specific features of each design will be analyzed for the trade-offs between cost, attenuation level, weight, assembly methods, and shipping volume.

Portable and permanent shelters will be treated in separate discussions, as different parameters are analyzed in each case. Charts will be presented that permit rapid comparison between the various classes of enclosure. Each point of comparison will then be discussed in detail.

2. PORTABLE ENCLOSURES

Four different types of portable enclosures have been developed to meet the requirements for attenuation level. Two options are presented for Class I, and one each for Class II and Class III. The Class I and II (see A100, Appendix III) configuration are 20' x 20' x 16' while the Class III (see A118, Appendix III) configuration is 16' x 38' x 10'.

The following table will list the various items to be compared between the four configurations.

TABLE I

<u>ENCLOSURE</u>	<u>ERECTION TIME</u>	<u>SHIPPING WEIGHT</u>	<u>SHIPPING VOLUME</u>	<u>MATERIAL COST</u>
Class I - Aluminum	60 mh	7,000	490 cu. ft.	19,320
Class I - Steel	60 mh	24,000	490 cu. ft.	20,017
Class II	60 mh	7,000	490 cu. ft.	19,320
Class III	80 mh	9,500	750 cu. ft.	13,432

The text in succeeding sections will elaborate on the comparisons and offer potential trade-offs and simplifications.

Erection Time

All estimates for erection time are based upon the use of a six-man crew. Also, at several periods during the assembly of the enclosure, more than one operation may be performed by separating the crew into several groups.

The basic assembly method would be to first install and level the jacks, floor beams, and floor panels (including flooring material). Wall and roof panels and their appropriate edge and corner extrusions would be partially pre-assembled and later put into place. Finally, the false roof, vents, door, filter panels, and interior lighting would be installed.

Shipping Weight

Weights shown in the Shipping Weight column of Table I are total package weights for each type of enclosure. They include the weight of all enclosure components, necessary packing material and a suitable shipping container. Approximately 15 to 20% of the total weight shown is that of the packaging materials.

Shipping Volume

Because of the high weight and delicate nature of the enclosure components, such as the honeycomb sandwich wall, roof, and floor panels and the more complex extrusions, it is necessary to

utilize carefully designed packaging method. The method selected was to use large plywood crates, built upon appropriate skids, in order to permit easy moving by standard cargo handling methods.

Class I and II enclosures may be shipped in one container, measuring approximately 20' 6" by 10' 6" by 2' 6". Interior packing material would be arranged to properly separate all of the panels and extrusions, and at the same time attempt to keep the center of gravity low enough to permit easy handling.

Two shipping crates would be necessary for the Class III enclosure. Since the edge extrusion and siding channels are 32 feet long, one container could be 32' by 2' by 2' and enclose all of the beams, edge extrusions, and other lengthy components. The second container, 8' by 11' by 5', would contain the honeycomb sandwich panels, end sections, and all other smaller size components.

Cost

Cost figures shown in Table I represent the total material cost to assemble each type of enclosure, on a production basis of fifty units produced as a single lot. Figures listed do not include any labor costs to erect the enclosure.

Material costs only are shown to permit comparison between the cost of various levels of attenuation, without regard to erection labor costs. Additional expenditures for labor to erect the shielded enclosures will vary from location to location to an extent to make any comparison meaningless.

If any given enclosure was to be produced in a single quantity, the cost would be double or triple that shown in Table I. This would be caused by higher material prices in small quantities, and by the fact that tooling and set-up charges would apply to only one enclosure, rather than fifty units.

Simplification and Cost Reduction

Table I lists the shipping weight, volume, erection time, and cost of each Class of enclosure; in the configurations described in Appendix III. Many areas for cost reduction and simplification exist that may be appropriate for certain applications.

If any of the enclosures described was to be erected on an existing concrete floor, runway apron, hardstand or other firm, relatively level surface, the floor leveling provisions and beams could be simplified or eliminated. In the Class I and II enclosures, this would reduce the shipping weight by about 700 lbs. (aluminum) or 1500 lbs. (steel); while cost would be reduced about \$700.00 in each case. Since the Class III floor beam is more complex and forms a part of the seam closure, the

reduction in weight would be only 500 lbs. and cost savings would be about \$400.00.

Erection times are based upon the use of expandable bushing type fasteners on all seams, which are very rapid to install and will repeat the required seam pressures with high accuracy. A significant reduction in cost (approximately \$3000) would result from the use of high strength bolts, or other suitable fasteners for the panel seams; however, the portion of set-up time devoted to seam closure would be increased by a factor of approximately 8 to 10. If the load ratings on the panels and structural members could be reduced, there could be a corresponding reduction in fastener cost and complexity. Further developments in fastener technology may also permit more economical joining methods to be employed.

A general reduction in enclosure cost could be made by considering the size requirements versus standard size structural panels and shapes. If the overall dimensions of panels and total enclosures were made to conform to industry standards, much time and expense could be saved through a reduction of cutting charges, special tooling, custom order charges, scrap material, or special handling charges. Again, a reduction in load requirements particularly roof dead load and wind loads; would permit the use of lighter extrusions and support members, and in some cases, thinner panel skins.

3. PERMANENT ENCLOSURES

Permanent shielded enclosures designed for the present application must meet the same requirements for attenuation level (see Appendix I, Fig. 1) as the portable shelters. However, only two configurations are necessary to meet the stated requirements.

Class II attenuation levels may be met using skins less than .050" thick (16 ga) as in Class I. However, structural requirements and fabrication problems such as MIG welding techniques dictate the use of at least 16 ga. panels for both Class I and II.

A completely different design concept is proposed for the Class III permanent enclosure. This design is intended to be used inside of an existing structure.

Table II below compares the various classes of enclosures from a cost standpoint only. As in the previous section, paragraphs following the table will describe some potential cost savings and simplifications.

TABLE II

<u>ENCLOSURE</u>	<u>COST OF MATERIALS</u>
Class I	\$20,579
Class II	\$20,579
Class III	\$ 5,422

Cost

The cost figures for the permanent shelters are once again material costs only. Variations in labor costs between various areas and labor markets would make any comparison of total cost of little value.

To give some idea of total assembly costs, however, it can be stated that the Class I and II enclosures would require about 2100 man-hours to erect. These enclosures are of an all-welded construction. Heavy equipment would be required to install the roof framing and floor support grid.

The Class III enclosure would take about 400 man-hours to install. Construction of this enclosure would consist of installing the plywood shell, affixing the aluminum panels with wood screws, and taping all panel seams with conductive tape.

Simplification and Cost Reduction

If the requirement for a raised floor was removed, and the Class I or II enclosures erected on a concrete slab, a cost savings of about \$2,500.00 would result. This would occur because of elimination of the floor beams, jacks, and skirt panels.

A further cost reduction of approximately \$800.00 would result from elimination of the peaked roof used in the Class I and II enclosures. The use of standard I beams in stock 20 ft. lengths would be the main factor in cost savings.

An interior concrete floor or some other suitable floor used in place of the Q-Deck section specified would further reduce the cost and assembly time.

APPENDIX I TEST DATA

Shielding Material Evaluations

Seam Testing

Enclosure Testing

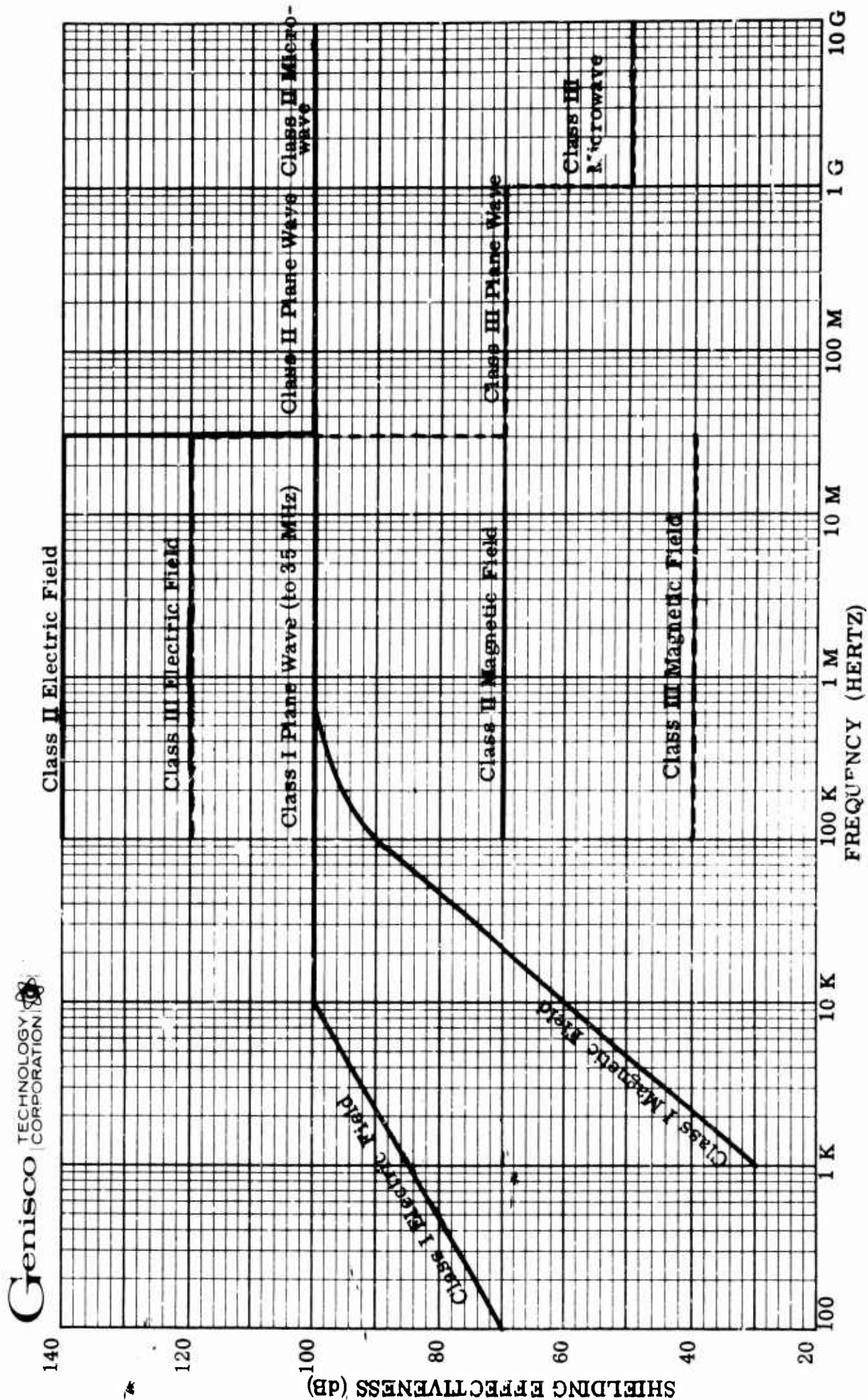


Figure 1 — Required Shielding Effectiveness for Class I, II and III Enclosures

Figure 2 - Details of Cylindrical
Fixture for Shielding
Efficiency Test

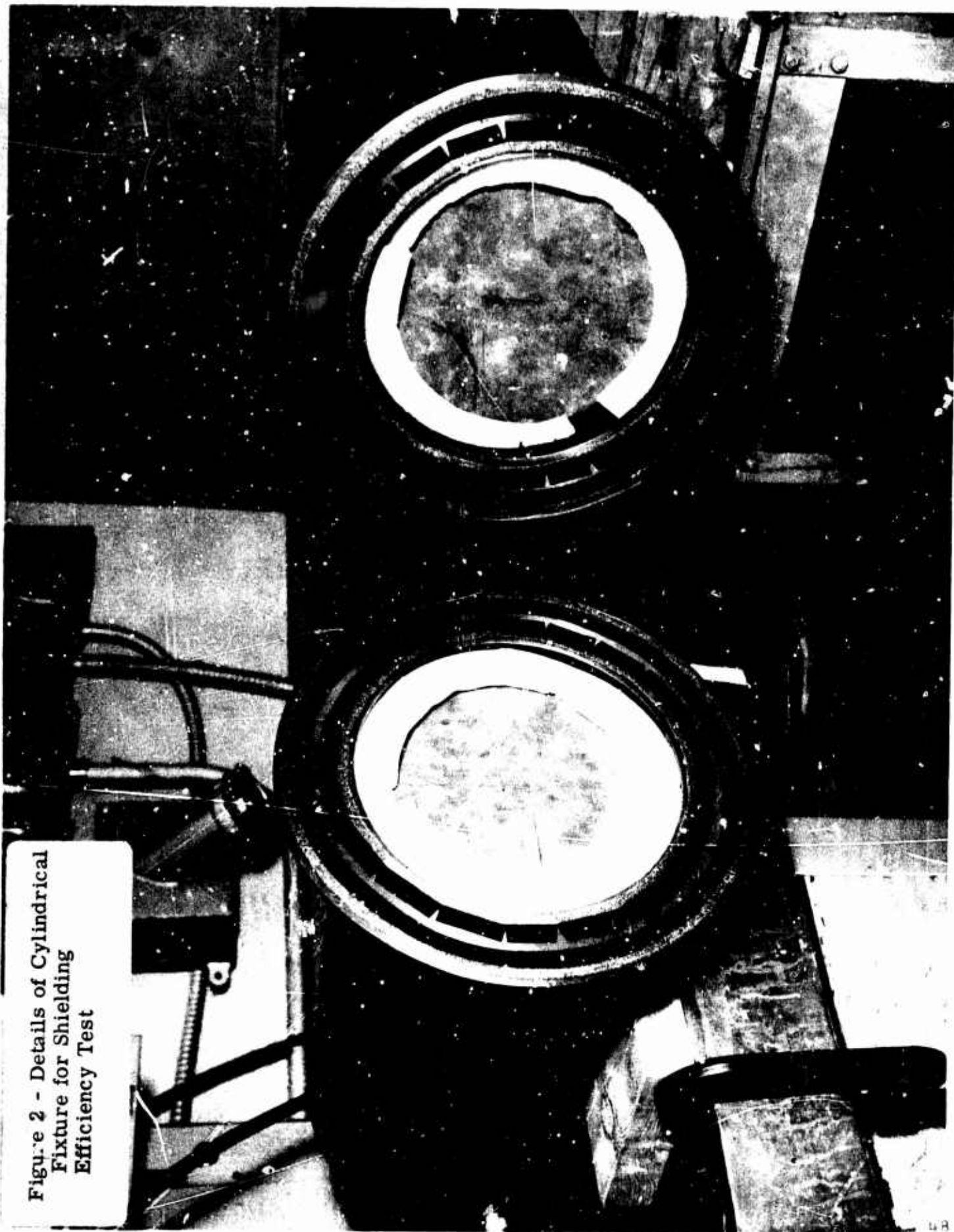


Figure 3 - Shielding Efficiency
Test in Cylindrical Fixture

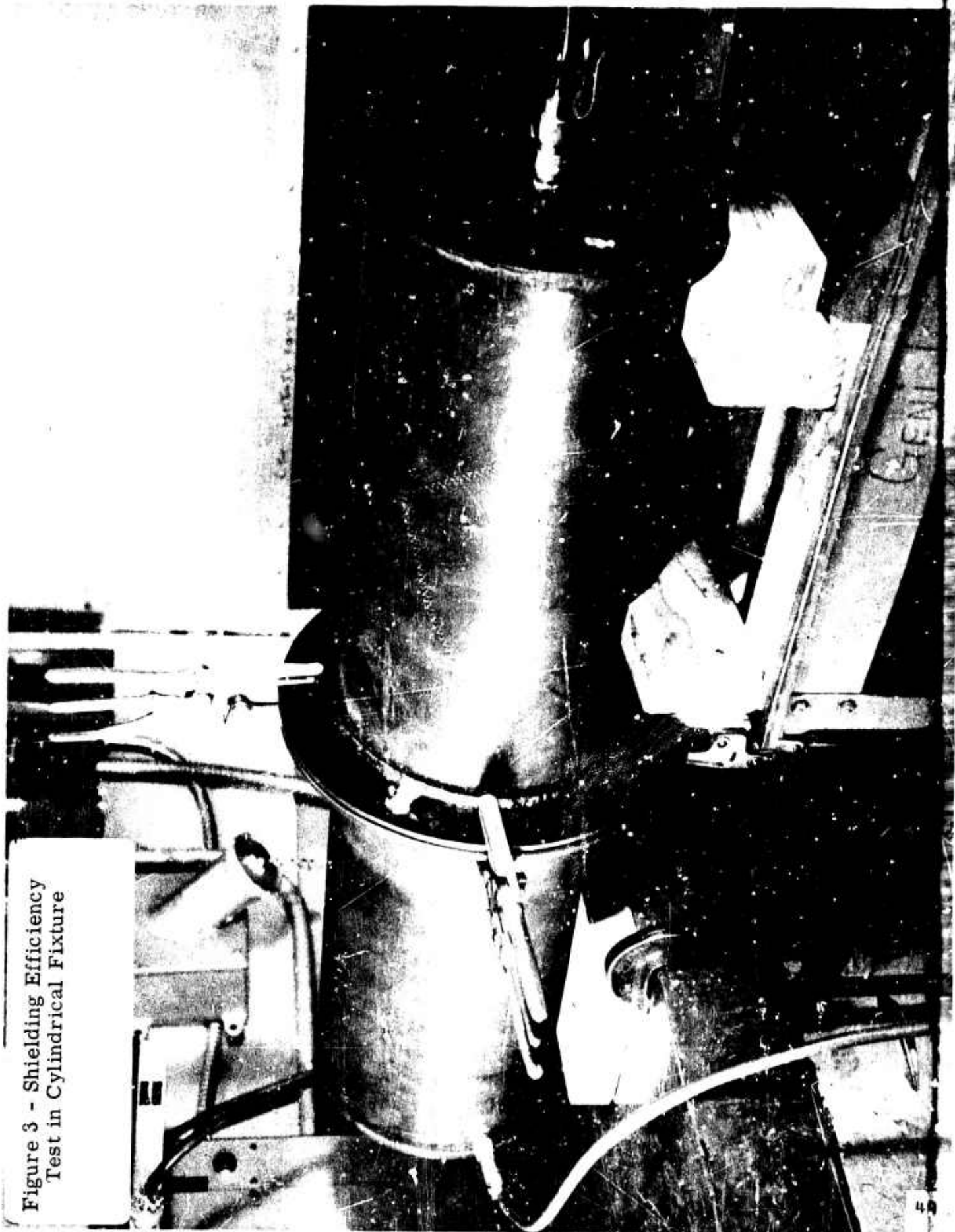


Figure 4 -- Microwave Testing
in the Shielded-Room Wall
Test Fixture

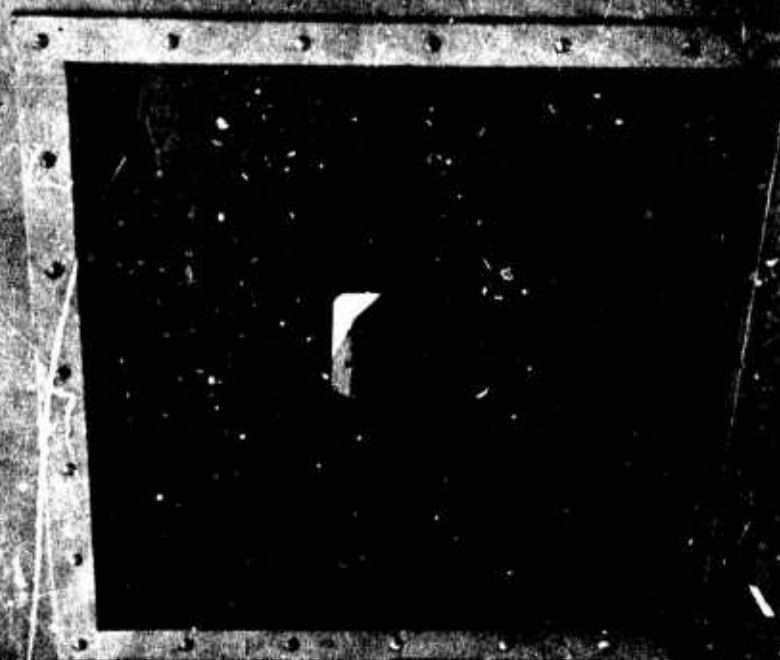




Figure 5 — Closeup of the
Shielded-Room Wall Test
Fixture

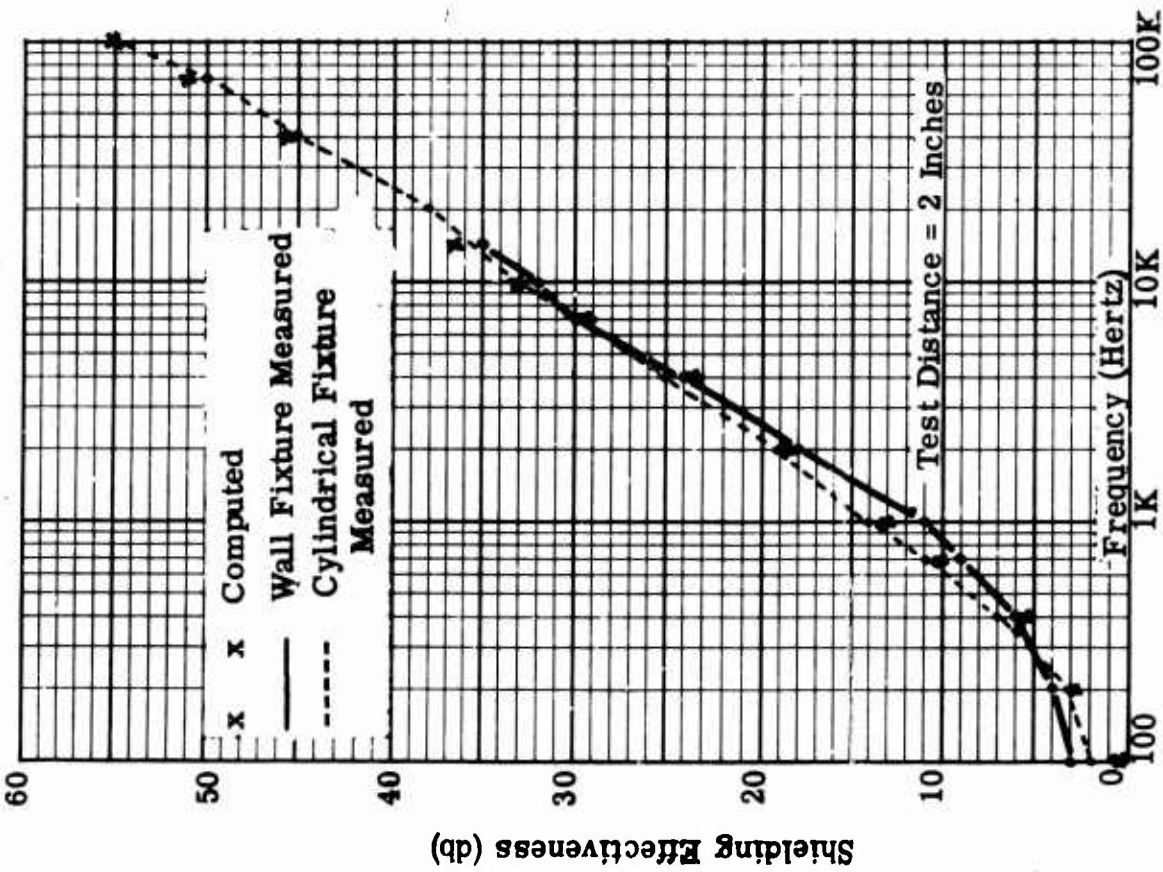


FIGURE 6 COMPUTED AND MEASURED MAGNETIC SHIELDING EFFECTIVENESS OF .0162 IN. THICK COPPER

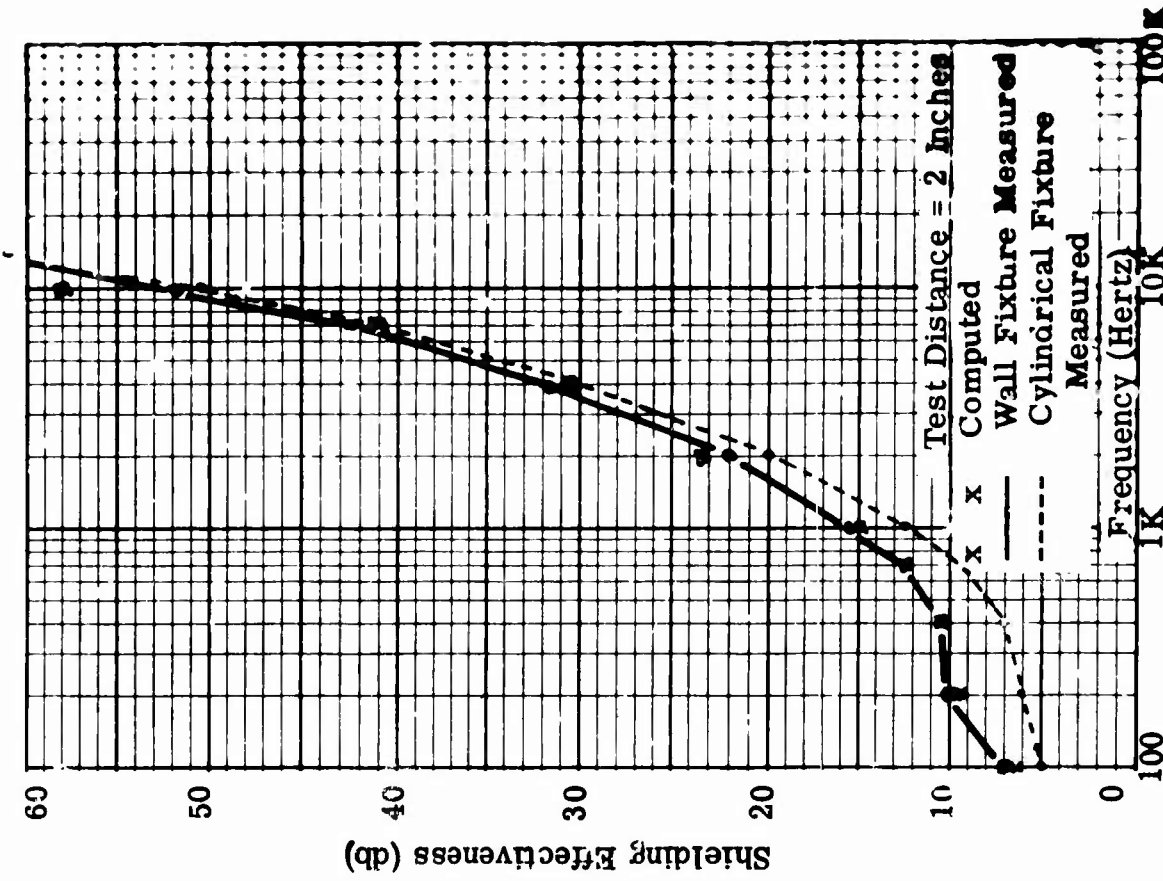


FIGURE 7 COMPUTED AND MEASURED MAGNETIC SHIELDING EFFECTIVENESS OF .0239 IN. THICK GALVANIZED STEEL

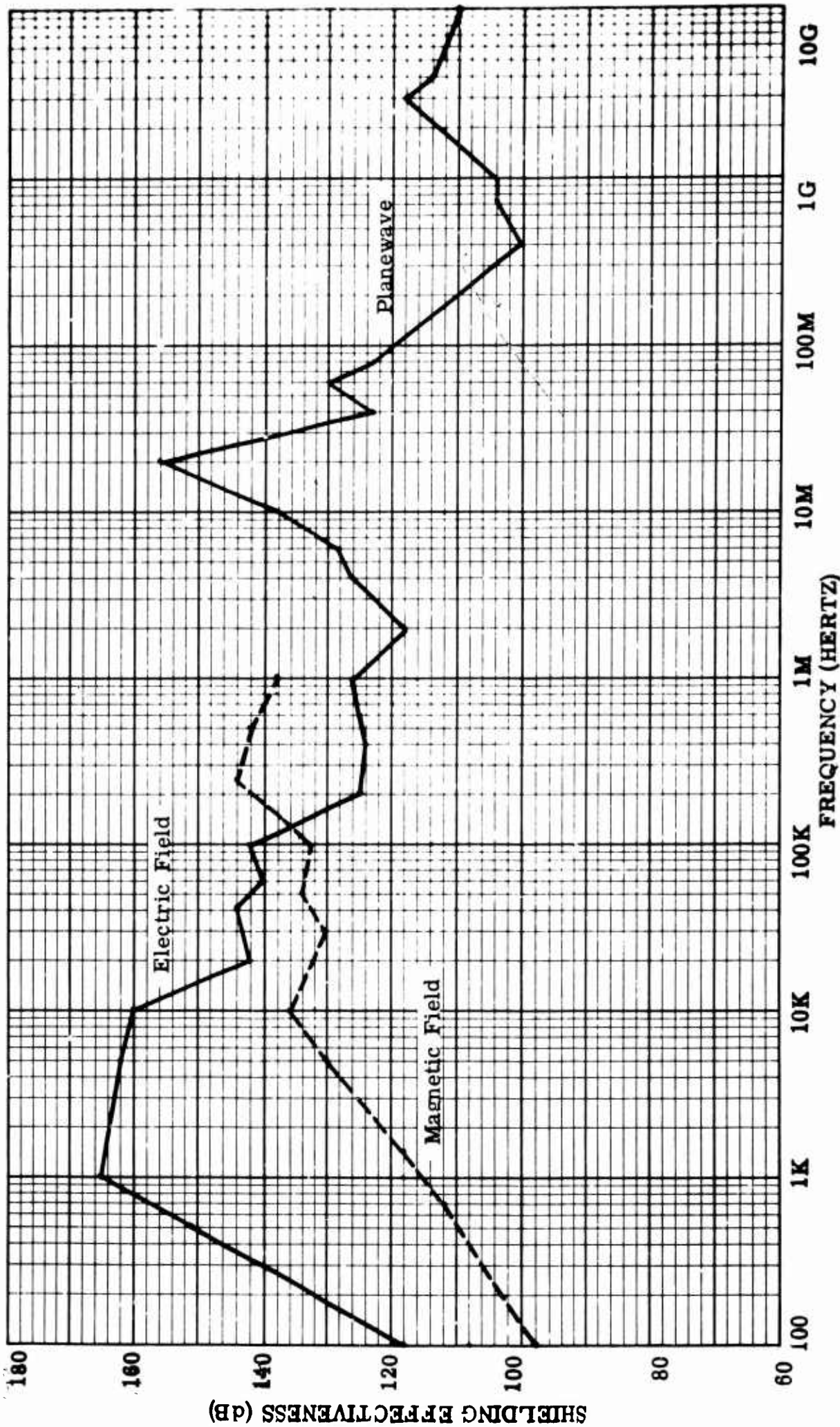
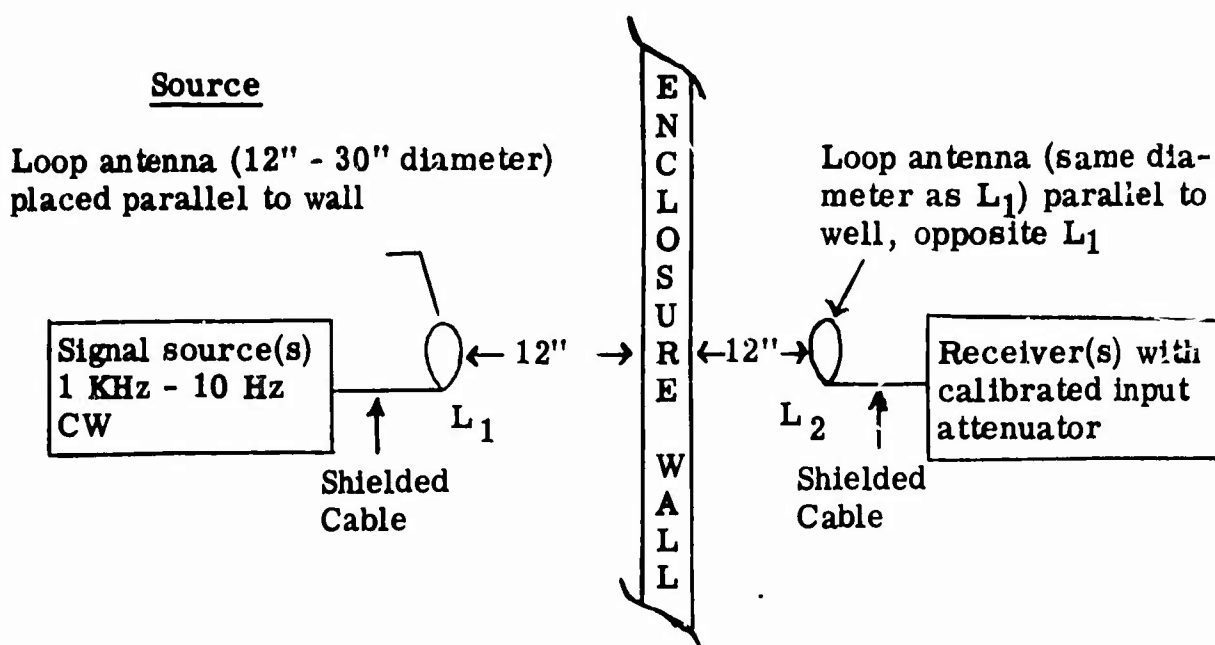


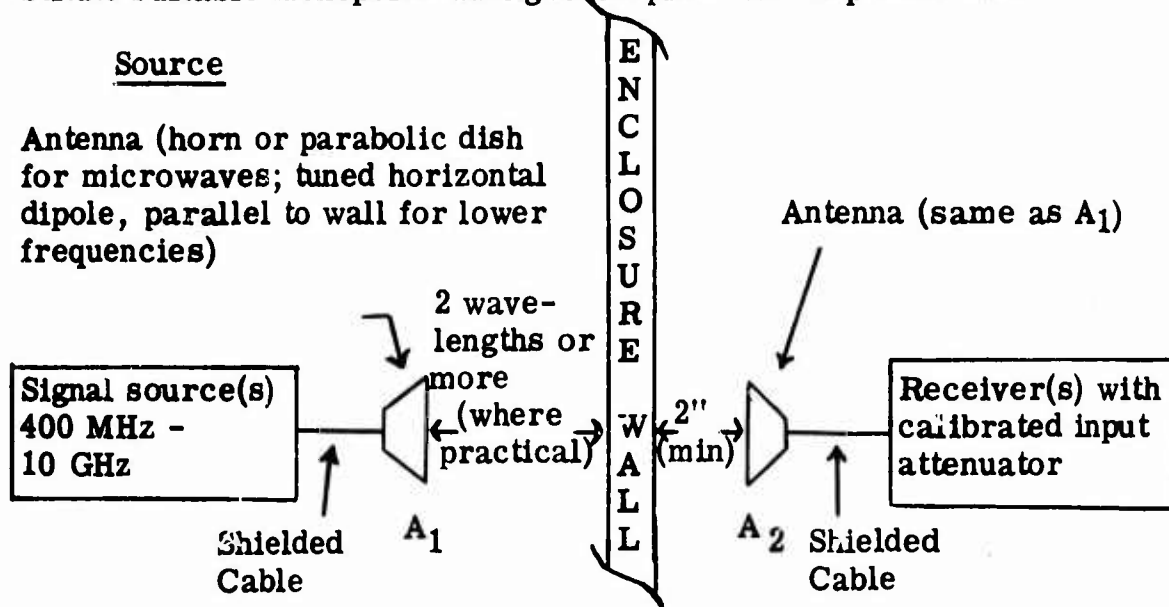
FIGURE 8 — TYPICAL DYNAMIC RANGE FOR ELECTRIC AND MAGNETIC FIELD AND PLANE WAVE TESTING USING THE CYLINDRICAL TEST FIXTURE

FIGURE 9 GENERAL TEST CONFIGURATION OF SHIELDING EVALUATIONS

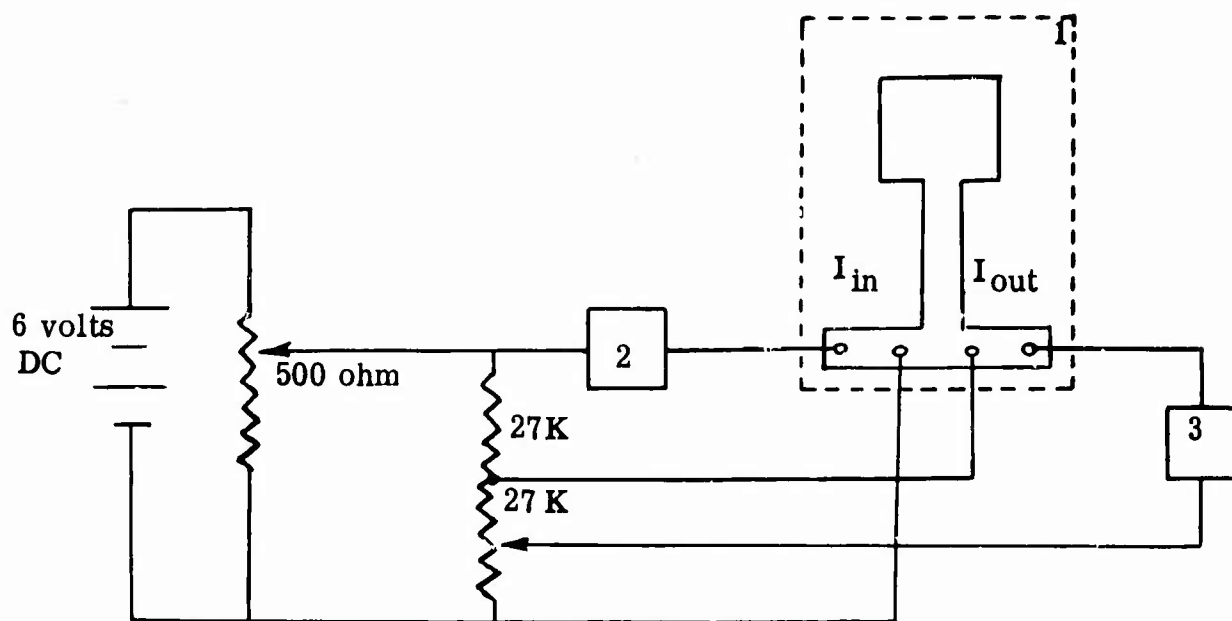


a) Test Setup for Magnetic Field Measurements (1 KHz - 10 MHz)

Note: Loop antennas must be positioned for maximum pick-up. For electric field measurements in this range, use same setup but substitute suitable monopoles with ground plane for loop antennas.



b) Test Setup for Plane Wave Measurements (100 MHz - 10 GHz)



1. Beckman Halleflex 1568 Probe
2. Simpson 1702 Milliampere Standard (to measure probe driving current I_{in})
3. HP 403A Millivoltmeter

Figure 10 — Magnetic Field Measurement Circuit

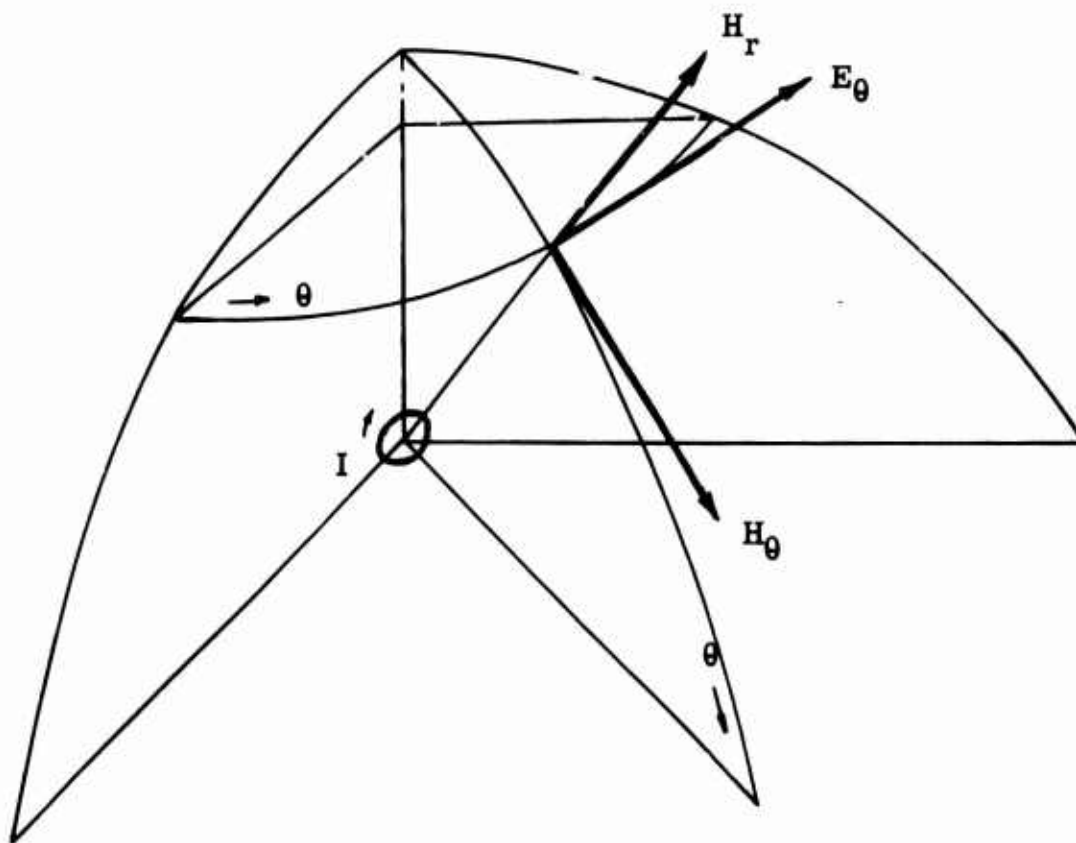
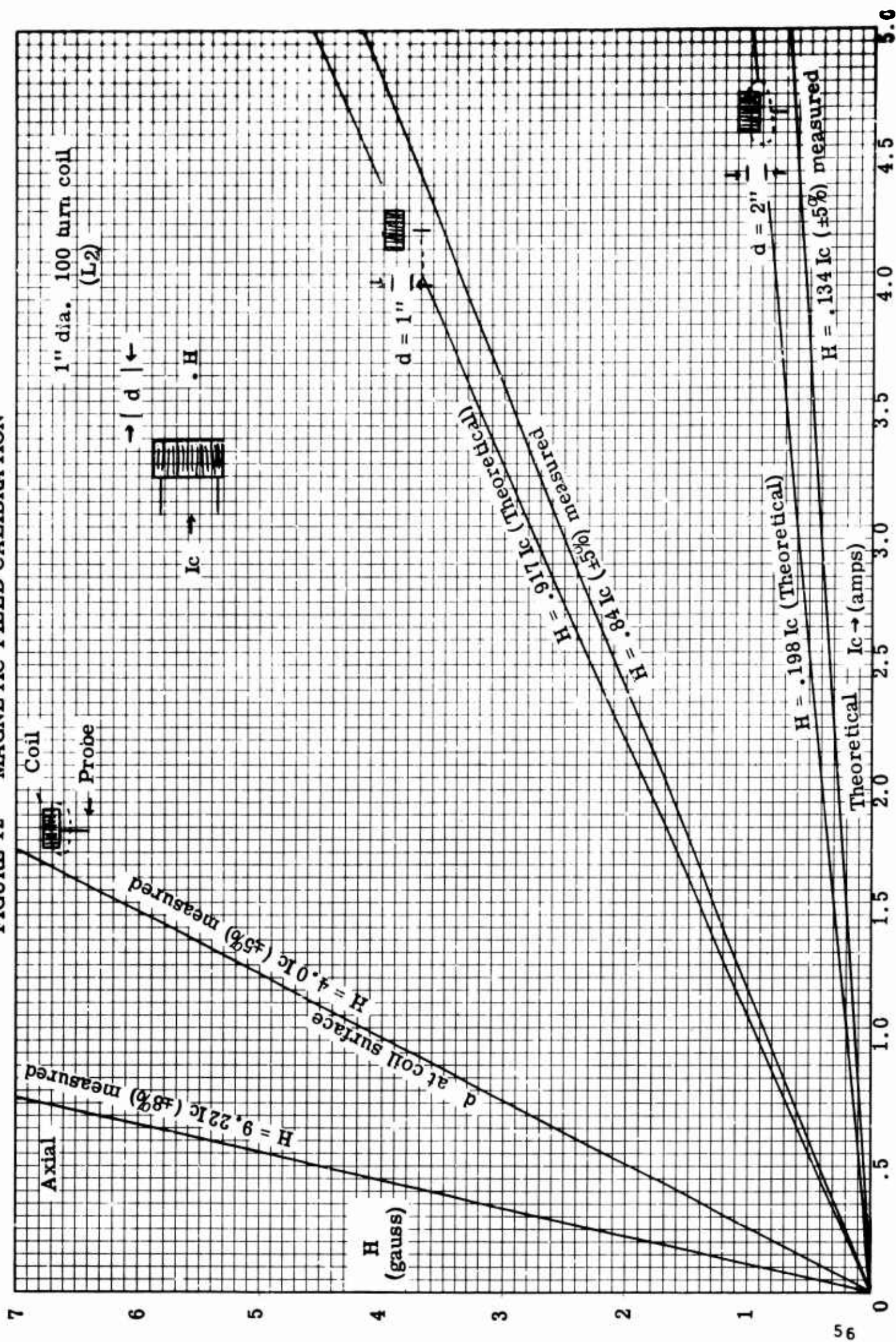


Figure 11 — Electric and Magnetic Field of a Small Loop Antenna

FIGURE 12 MAGNETIC FIELD CALIBRATION



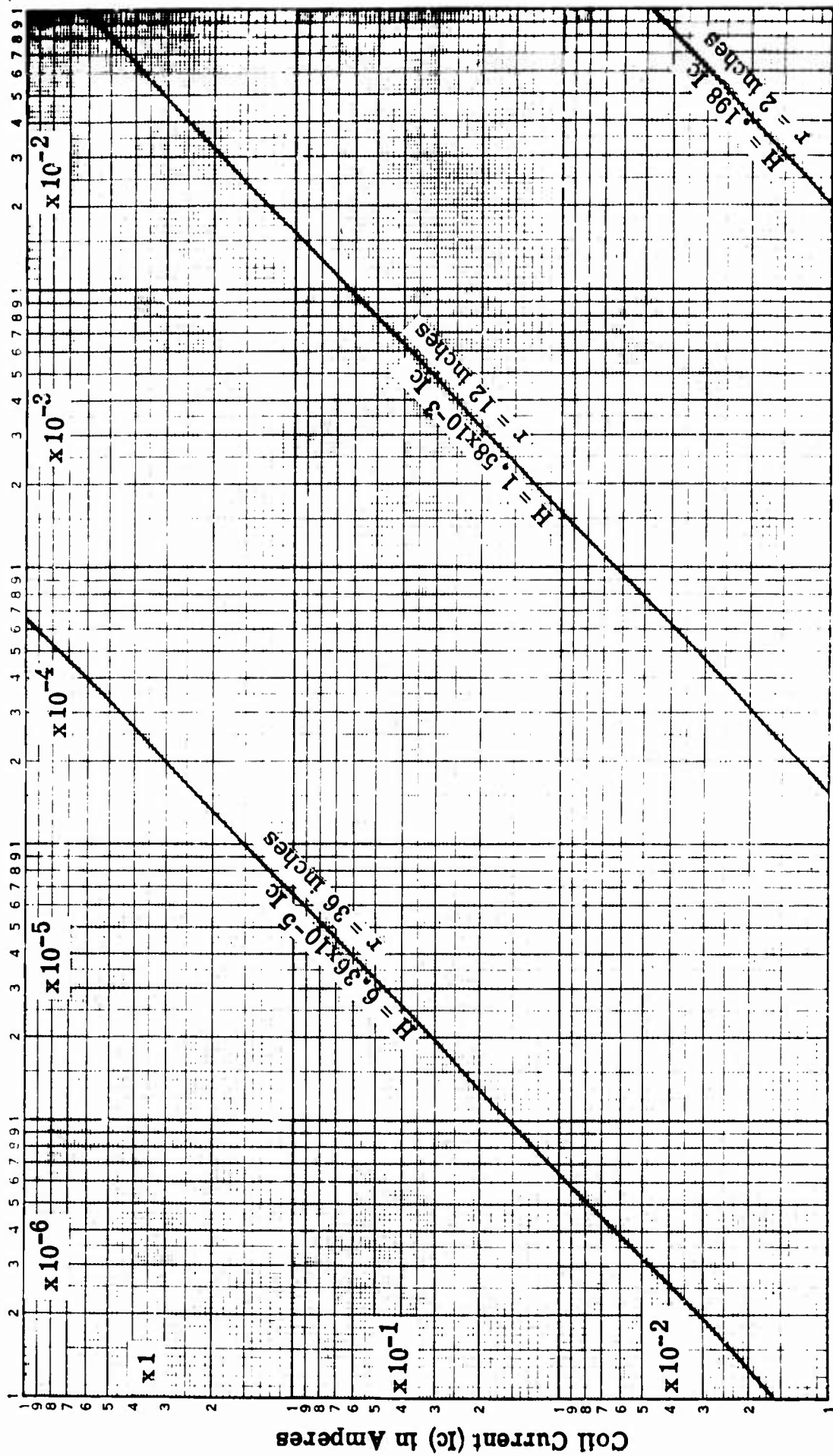


FIGURE 13 THEORETICAL MAGNETIC FIELD INTENSITY (H IN ORSTEADS) OR FLUX DENSITY (B IN GAUSS)

FIGURE 14 MATERIALS SUMMARY

CLASS I

<u>MATERIAL TYPE</u>	<u>MINIMUM THICKNESS</u>
Steel, Terne	0.0478 (18ga)
Steel, Hot Rolled	0.0478 (18ga)
Steel, Cold Rolled	0.0478 (18ga)
Steel, Galvanized	0.035 (20ga)
Primag (90)	0.040
Primag (40)	0.040
Copper and Galvanized Steel (.006 + .024)	.006 + .024 = .030

CLASS II

<u>MATERIAL TYPE</u>	<u>MINIMUM THICKNESS</u>
Aluminum	0.0598 (14ga)
Copper	0.0377 (19ga)
Steel, Galvanized	0.0092 (33ga)
Steel, Terne	0.013 (29ga)
Steel, Cold Rolled	0.013 (29ga)
Steel, Hot Rolled	0.013 (29ga)

CLASS III

<u>MATERIAL TYPE</u>	<u>MINIMUM THICKNESS</u>
Aluminum Foil	0.006
Copper Foil	0.006
Copper Foil (Tinned)	0.006
Primag Foil (90)	0.004
Flame Spray (Aluminum)	0.040
Flame Spray (Zinc)	0.040
Flame Spray (Copper-Zinc)	0.020

Note: Material for Class I can be used for Class II or III and materials for Class II can be used for Class III.

FIGURE 15 MAGNETIC FIELD PERFORMANCE OF PERMANENT SEAMS AT TWO INCH TEST DISTANCE

<u>SEAM TYPE</u>	<u>CLASS III</u>	<u>CLASS II</u>	<u>CLASS I</u>
<u>Butt Type</u>			
77 Bare Butt	O	O	O
78 Soldered	X	X	O
79 Copper Taped	X	O	O
80 Zinc Flame Spray	X	X	X
81 Copper Flame Spray	X	X	X
82 TIG Weld	X	X	marginal
83 MIG Weld	X	X	marginal
84 Silver Solder	X	X	O

<u>SEAM TYPE</u>	<u>CLASS III</u>	<u>CLASS II</u>	<u>CLASS I</u>
<u>Overlap Type</u>			
85 Bare Overlap	X	O	O
86 Soldered	X	X	X
87 Copper Taped	X	X	O
88 Zinc Flame Spray	X	X	X
89 Copper Flame Spray	X	X	X
90 TIG Weld	X	X	marginal
91 MIG Weld	X	X	X
92 Silver Solder	X	X	marginal

X - Complies to requirement
O - Noncompliant to requirement

FIGURE 18 PERFORMANCE OF PORTABLE SEAMS AND DOORS AT 12 INCH DISTANCE

WALL SEAM TYPE	ELECTRIC FIELD COMPLIANCE			MAGNETIC FIELD COMPLIANCE		
	CLASS III	CLASS II	CLASS I	CLASS III	CLASS II	CLASS I
1. New*	X	X	X	X	X	X
2. Old	X	O	O	X	X	O
3. Old	O	O	O	X	X	O
4. New	X	X	X	X	X	X
5. New	X	X	X	X	X	X
6. New	X	X	X	X	X	X
7. Old				X	X	X

CORNER SEAM
TYPE

1. New	X	O	O	X	X	X
2. Old	X	O	O	X	X	O
3. Old	O	O	O	X	O	O
4. New	X	X	X	X	X	X
5. New	X	X	X	X	X	X
6. New	X	X	X	X	X	X

DOOR TYPE

1. New	X	O	O	X	X	X
2. Old	O	O	O	X	X	X
3. Old	O	O	O	X	O	O
4. New	X	X	X	X	X	O
5. New	X	marginal	marginal	X	X	X
6. New	X	X	X	X	X	X

X - Complies to requirement
O - Noncompliant to requirement

* NOTE: Type numbers refer to Figure i0 of the May Monthly Report

Figure 17 - Basic Materials for Magnetic Field Tests

Sample No.	Material Type	Thickness (inches)
1	Copper (alloy 100 soft)	.0377
2	Copper (alloy 100 soft)	.0377
3	Copper (alloy 100 soft)	.0162
4	Copper (alloy 100 soft)	.0162
5	Aluminum (1100-1)	.0299
6	Aluminum (1100-0)	.0299
7	Aluminum (1100-H 14)	.0149
8	Aluminum (1100-H 14)	.0149
9	Galvanized steel	.0749
10	Galvanized steel	.0749
11	Galvanized steel	.0478
12	Galvanized steel	.0478
13	Galvanized steel	.0239
14	Galvanized steel	.0239
15	Terne steel	.0239
16	Terne steel	.0239
17	Terne steel	.0478
18	Terne steel	.0478
19	Hot-rolled steel	.0478
20	Hot-rolled steel	.0478
21	Aluminum	.0598
22	Aluminum	.0598
23	Cold-rolled steel	.0897
24	Cold-rolled steel	.0897
25	Cold-rolled steel	.0478
26	Cold-rolled steel	.0478
27	Cold-rolled steel	.0239
28	Cold-rolled steel	.0239
29	Tinned copper foil	.006
30	Combination of samples 24 and 29	.0957
31	Combination of samples 19 and 29	.0538
32	Combination of samples 15 and 29	.0299
33	Netic/conetic material	.004
34	Primac 40	.004
35	Primac 40	.060

Figure 17 - Basic Materials for Magnetic Field Tests (continued)

Sample No.	Material Type	Thickness (inches)
36	Primac 90	.004
37	Primac 90	.060
38	Hipernom (Westinghouse)	.006
39	Aluminum foil	—
40	Aluminum foil	—
41	5-mil Kapton-1.5-mil copper	—
42	Type KX shielding	—
43	Conetic AA	—

FIGURE 17 - BASIC MATERIALS AND COMPOSITES FOR SHIELDING TESTS

Sample No.	Material Type	Thickness (Inches)
44	Hot-rolled steel	.077
45	Hot-rolled steel	.077
46	Flame-sprayed copper	.020
47	Flame-sprayed aluminum	.040
48	Flame-sprayed zinc	.040
49	Flame-sprayed spray steel LS	.034
50	Flame-sprayed spray steel 80	.050
51	Flame-sprayed spray steel 10	.024
52	Flame-sprayed metcoloy #2	.020
53	Flame-sprayed metcoloy #4	.060
54	Copper foil	.011
55	Stainless steel	.003
56	Marquisette (heavy) metallized woven nylon	20 strands/in.
57	Woven metal sock	18 strands/in.
58	Monel wire cloth	100 mesh
59	Monel wire cloth	200 mesh
60	Light rip stop metallized woven nylon	
61	Heavy rip stop metallized woven nylon	
62	Copper screen	100 mesh
63	Inflatable screen rubber	
64	Inflatable screen rubber	
65	Inflatable screen rubber	
66	Galvanized steel screen	8 mesh
67	Galvanized steel screen	2 mesh
68	Aluminum screen	18 mesh
69	Chicken wire	1 inch opening
70	1-mil kapton -.4 mil copper type K (heavy)	.0014
71	1-mil kapton -1.2 mil nickel-iron alloy type X	.0022
72	1/16" felt metal stainless steel filled	
73	Sn/Cu/Fe mesh (woven)	
74	Expanded metal (monel)	16 mesh
75	Expanded metal (monel) silicon filled	16 mesh
76	Confuzz	

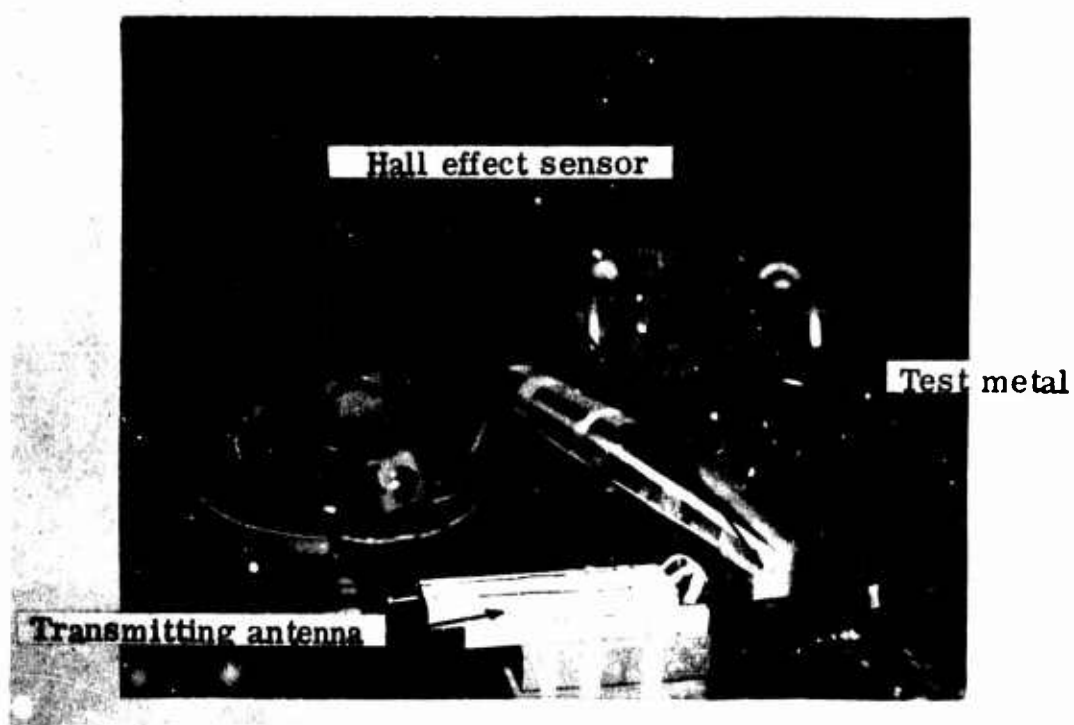


FIGURE 18 MAGNETIC FIELD INTENSITY AT METAL SURFACES

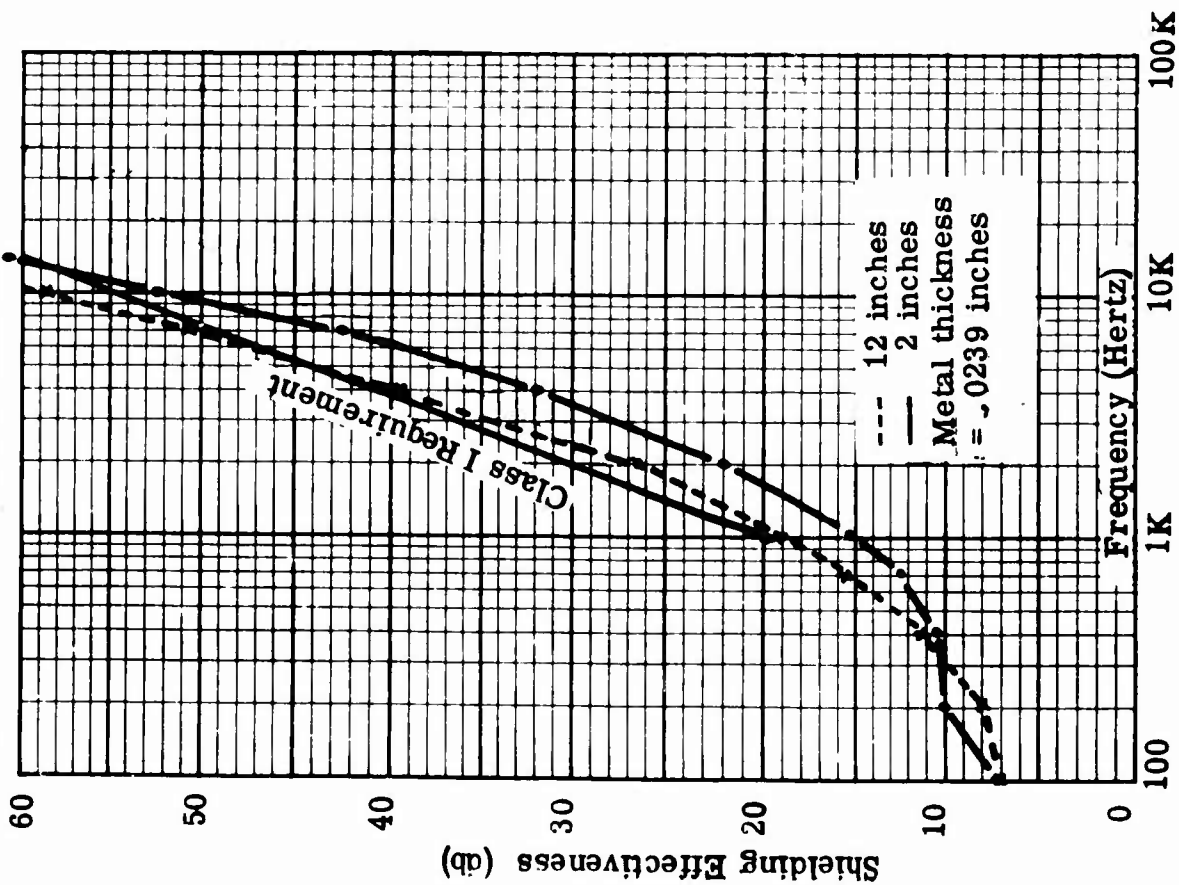


FIGURE 19 MAGNETIC SHIELDING EFFECTIVENESS OF GALVANIZED STEEL AT DIFFERENT TEST DISTANCES

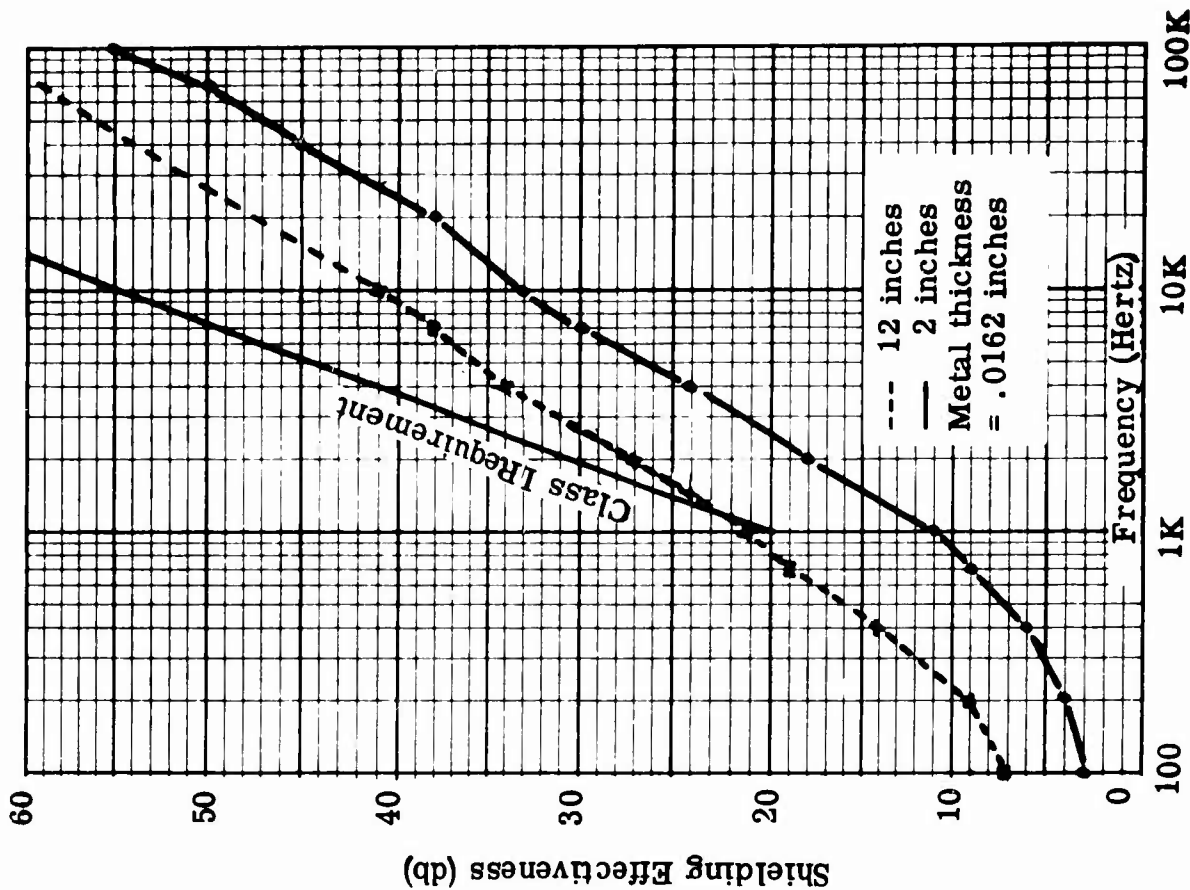


FIGURE 20 MAGNETIC SHIELDING EFFECTIVENESS OF COPPER AT DIFFERENT TEST DISTANCES

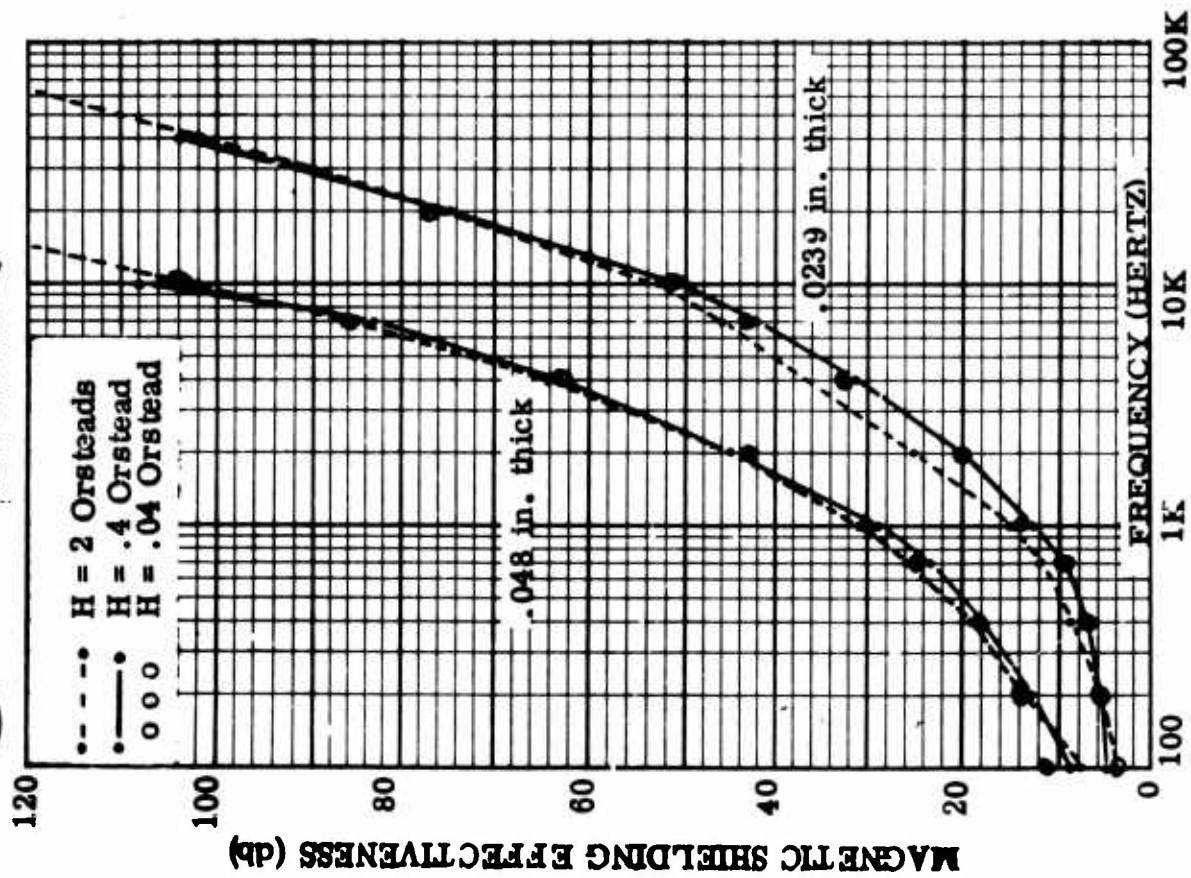


FIGURE 21 SATURATION EFFECT ON GALVANIZED STEEL

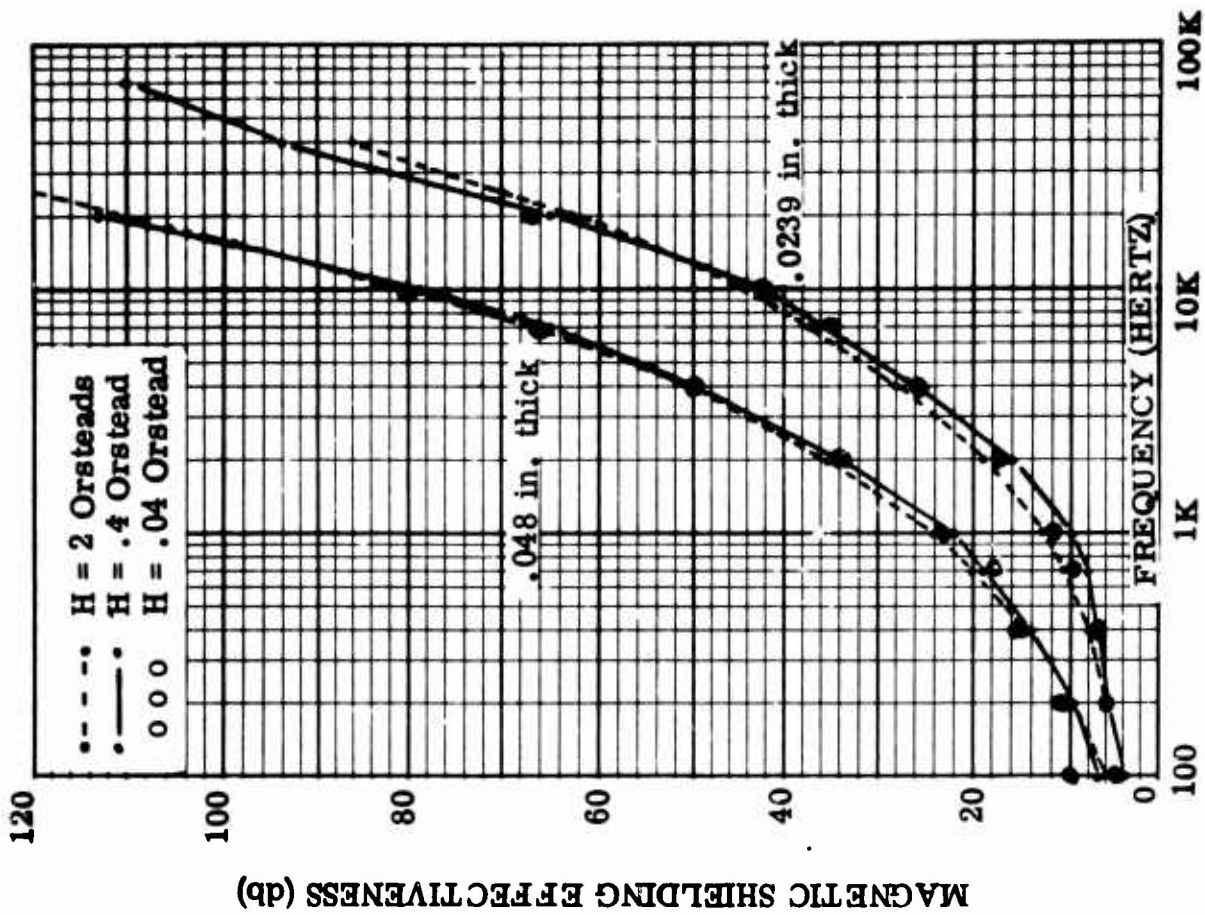


FIGURE 22 SATURATION EFFECT ON TERNE STEEL

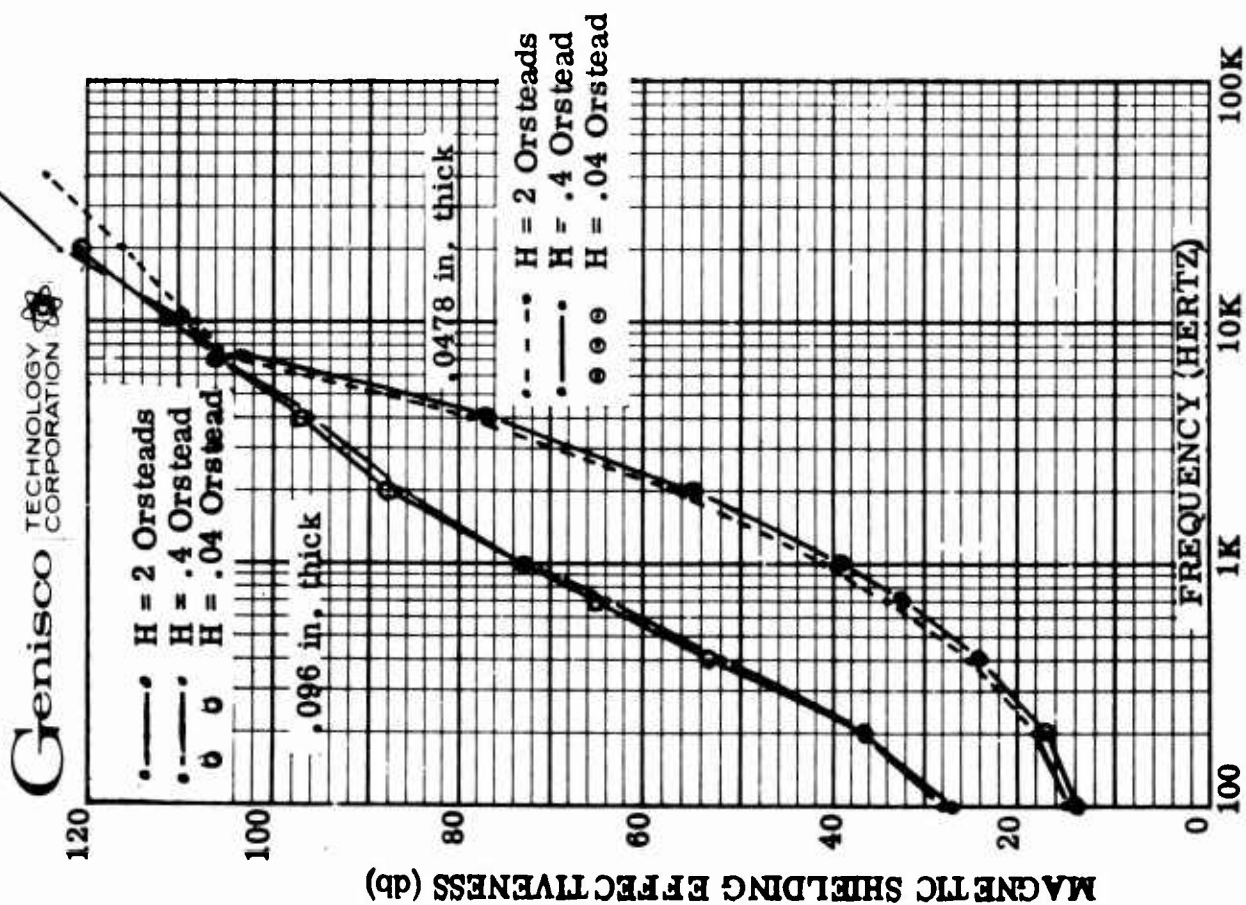


FIGURE 23 SATURATION EFFECT ON
HOT-ROLLED STEEL

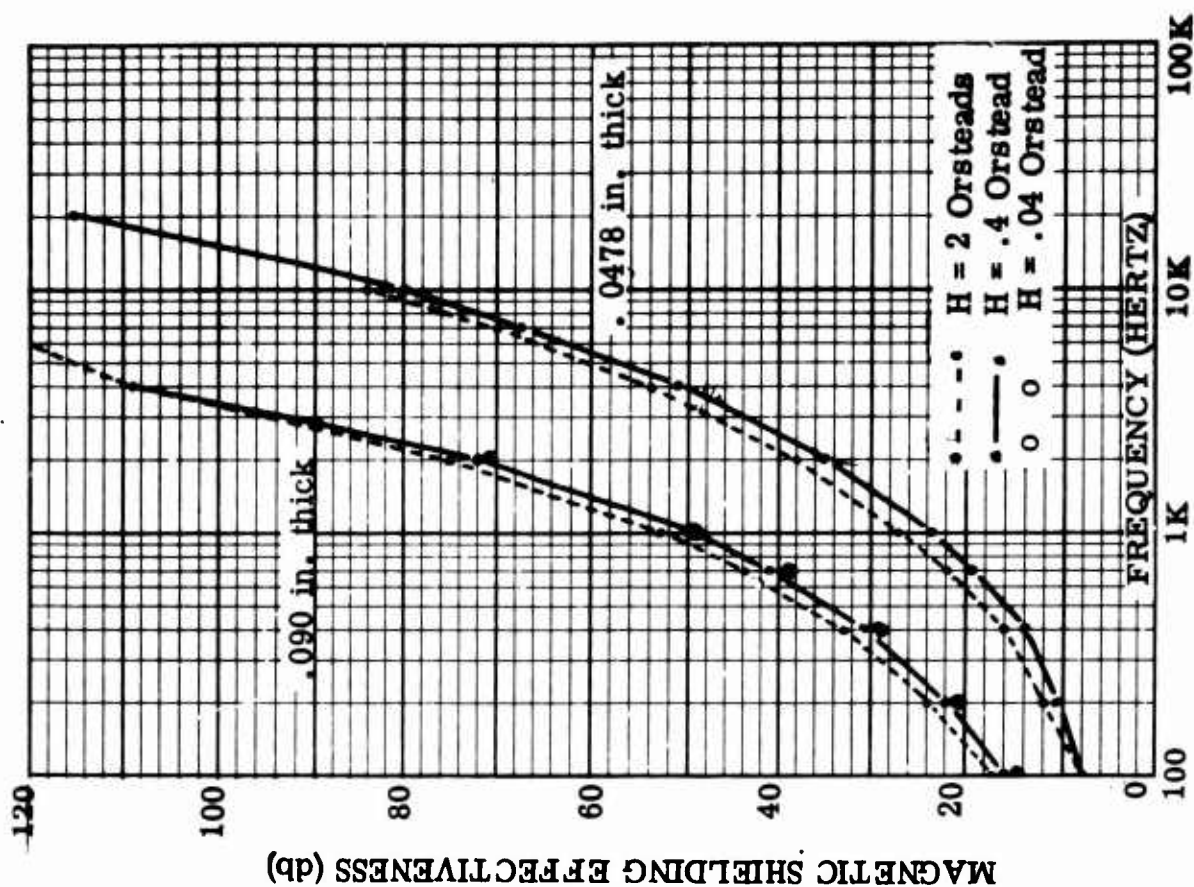


FIGURE 24 SATURATION EFFECT ON
COLD-ROLLED STEEL

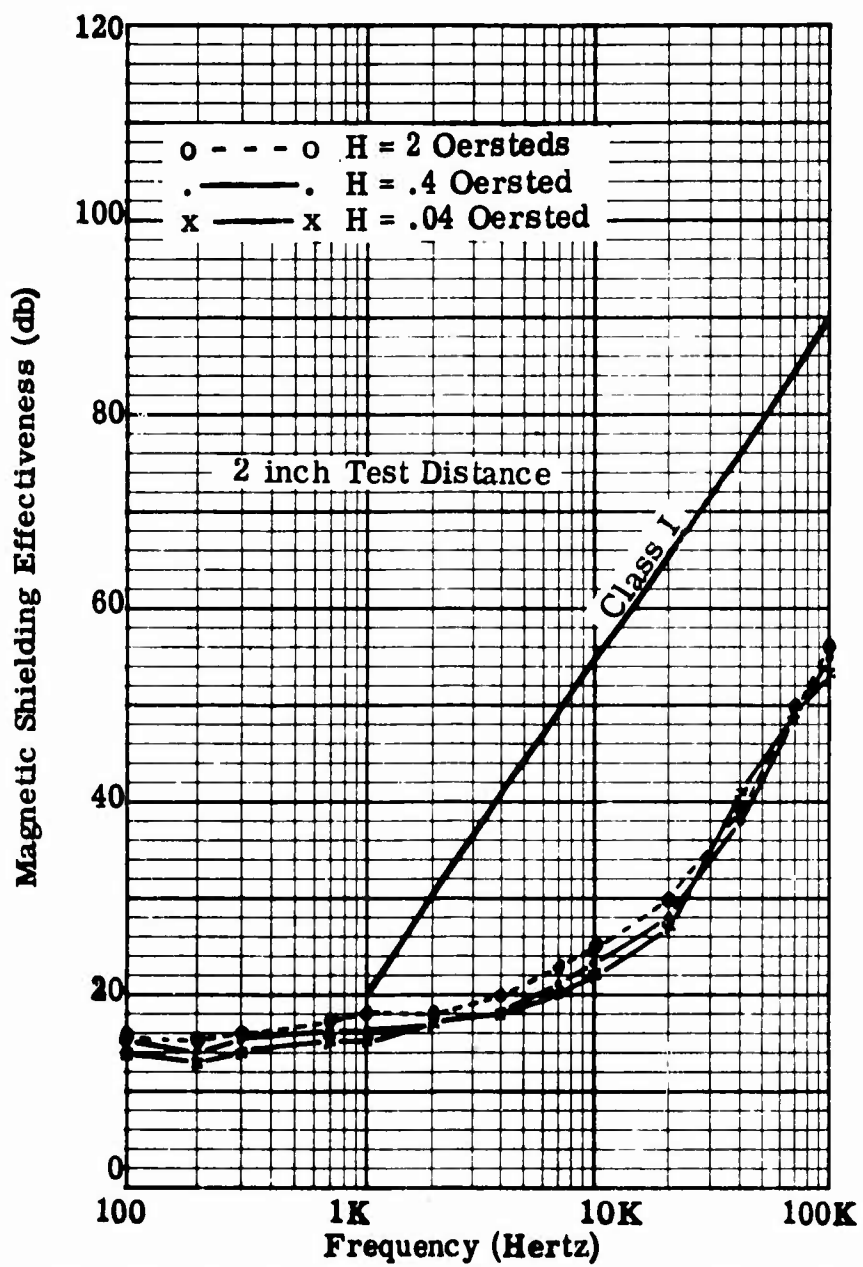


FIGURE 25 SATURATION EFFECT ON PRIMAG
 90 SHIELDS (.004 IN. THICK)

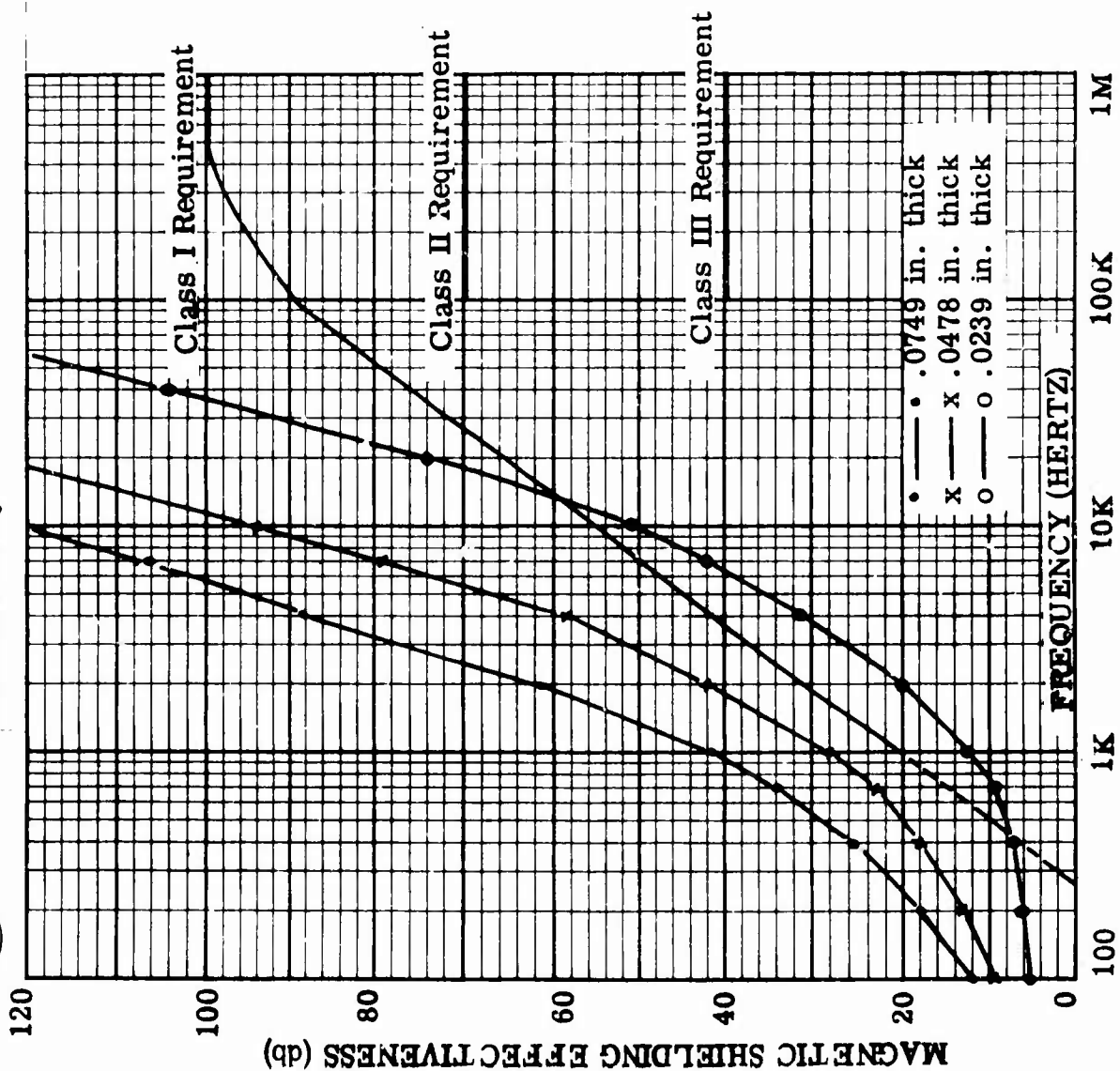


FIGURE 26 MAGNETIC SHIELDING EFFECTIVENESS OF GALVANIZED STEEL ($r = 2$ in.)

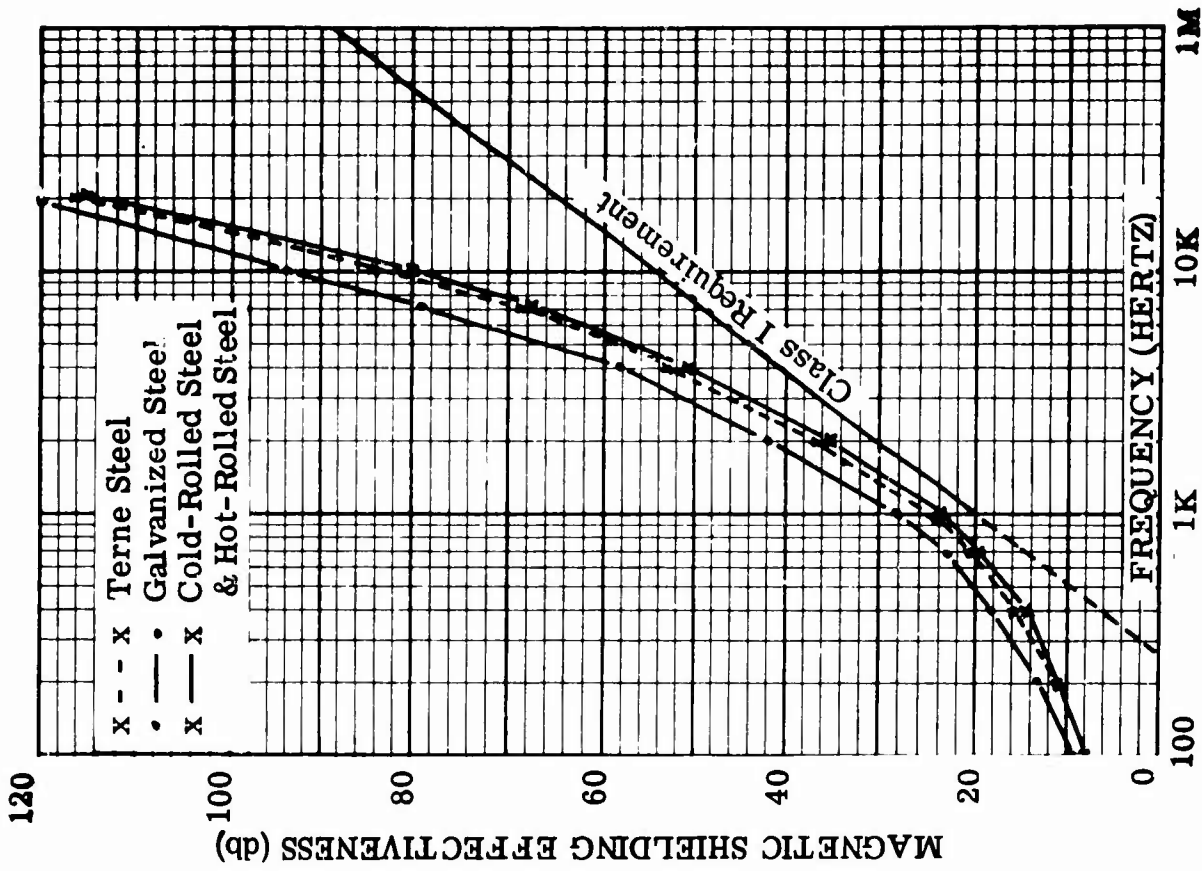


FIGURE 27 MAGNETIC SHIELDING EFFECTIVENESS OF .0478 IN. THICK FERROUS METALS

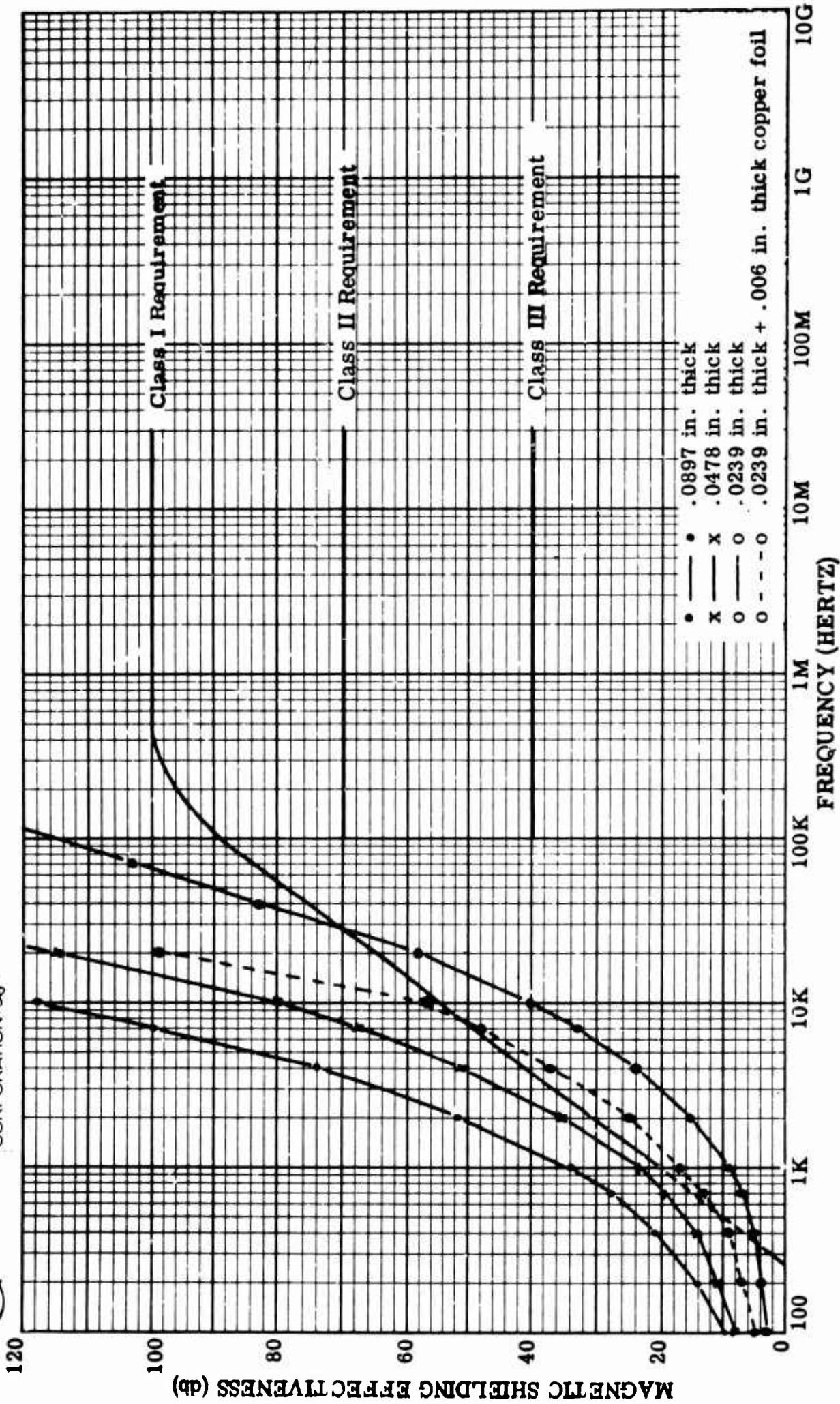


FIGURE 28 MAGNETIC SHIELDING EFFECTIVENESS OF COLD-ROLLED STEEL ($r = 2$ in.)

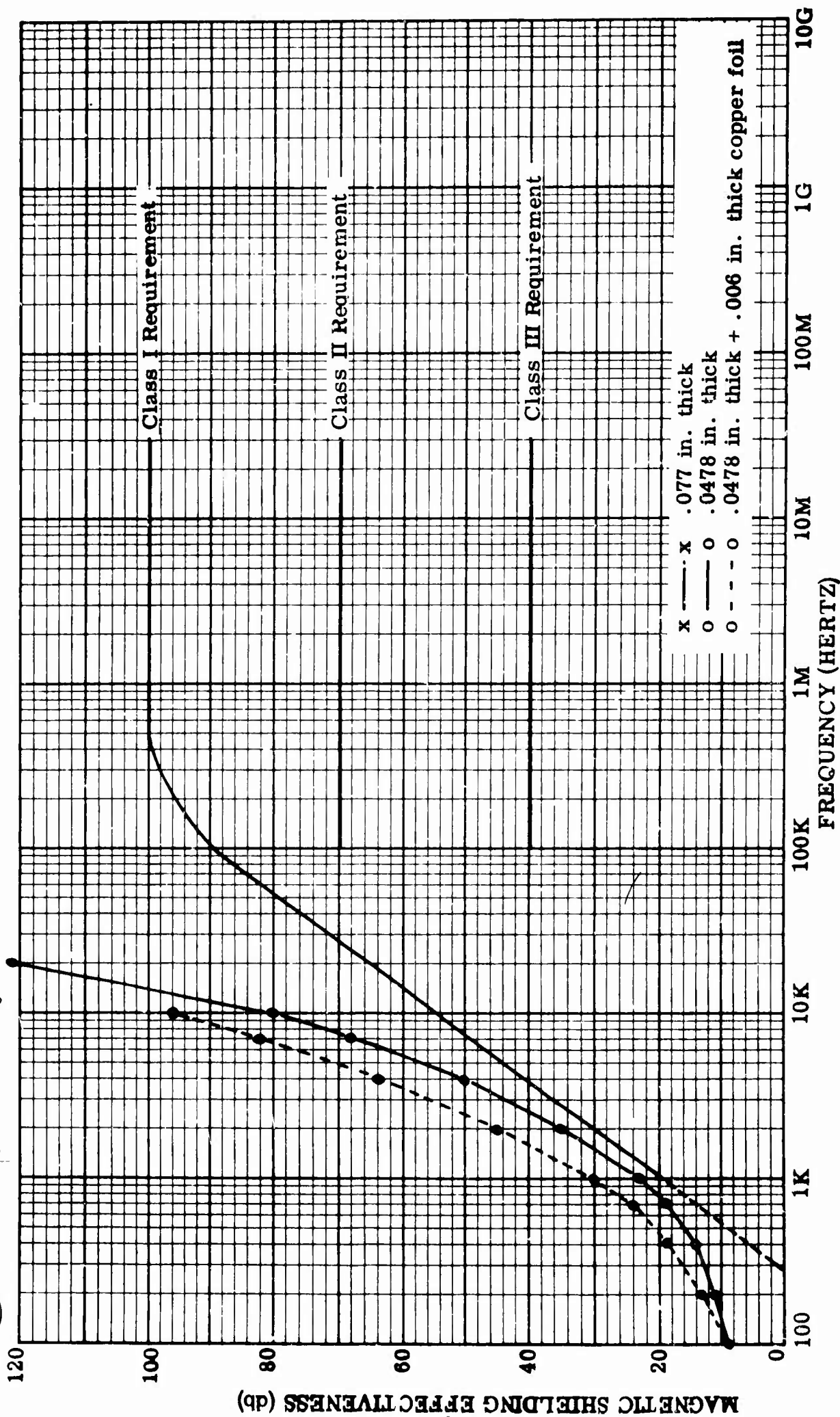


FIGURE 29 MAGNETIC SHIELDING EFFECTIVENESS OF HOT-ROLLED STEEL ($r = 2$ in.)

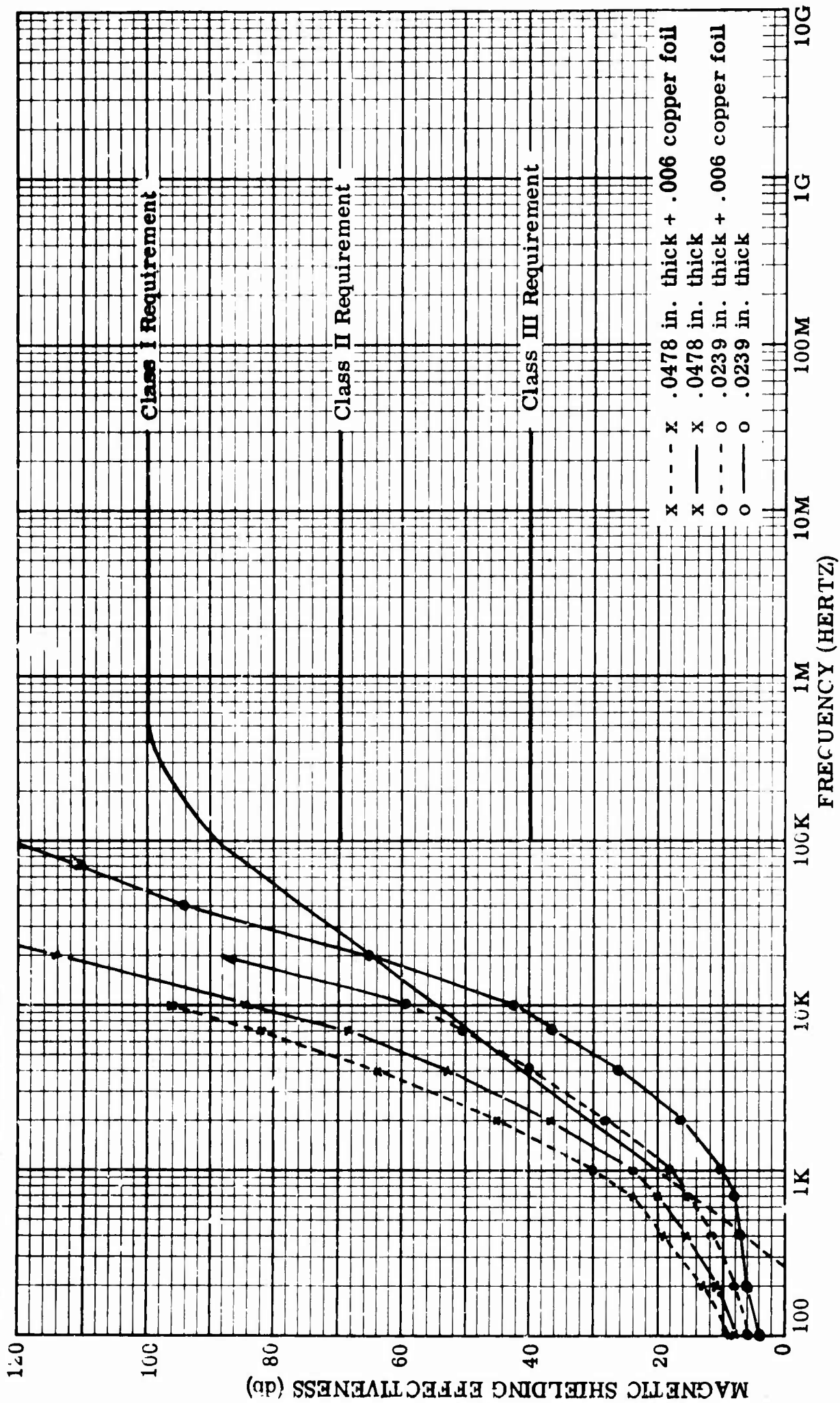


FIGURE 30 MAGNETIC SHIELDING EFFECTIVENESS OF TERNE STEEL (r = 2 in.)

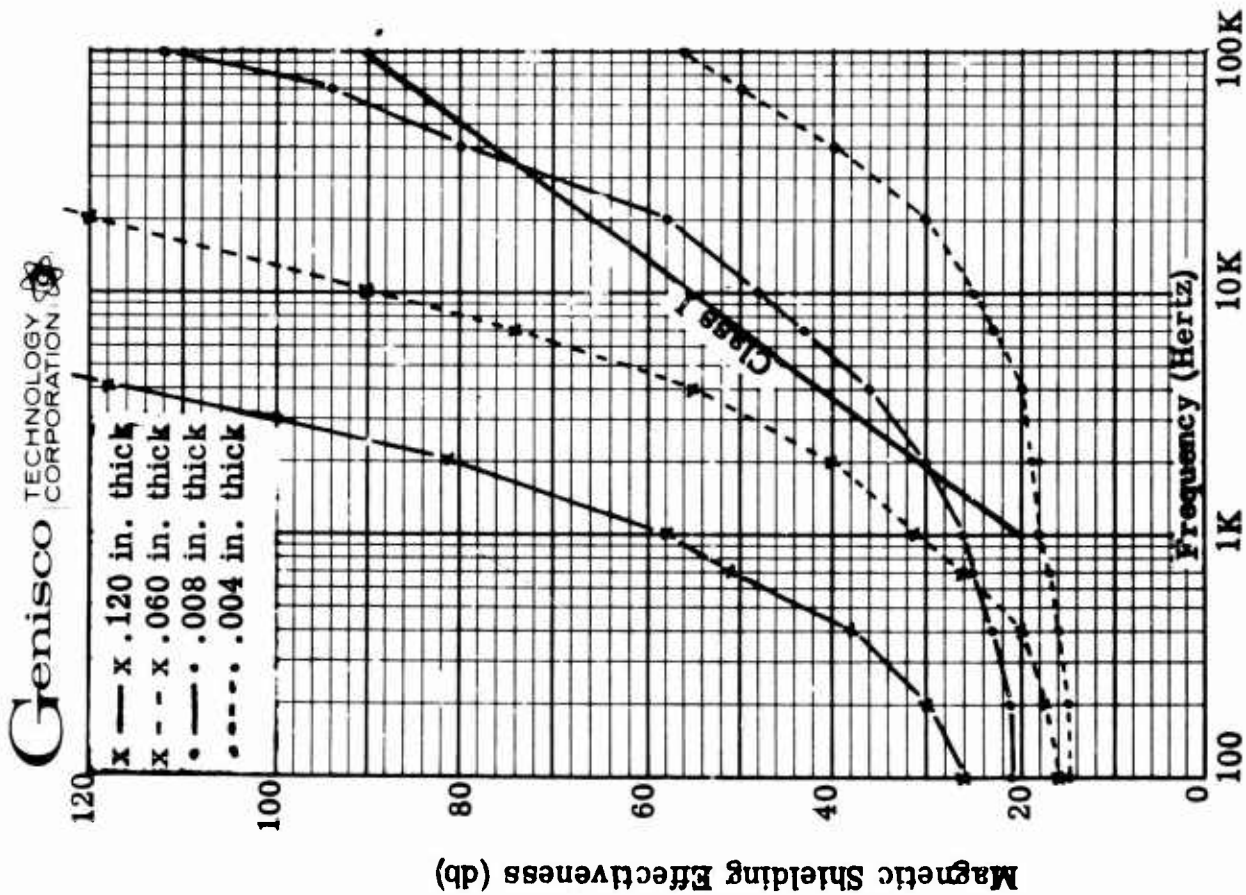


FIGURE 31 MAGNETIC SHIELDING EFFECTIVENESS OF PRIMAG 90 AT TWO INCHES

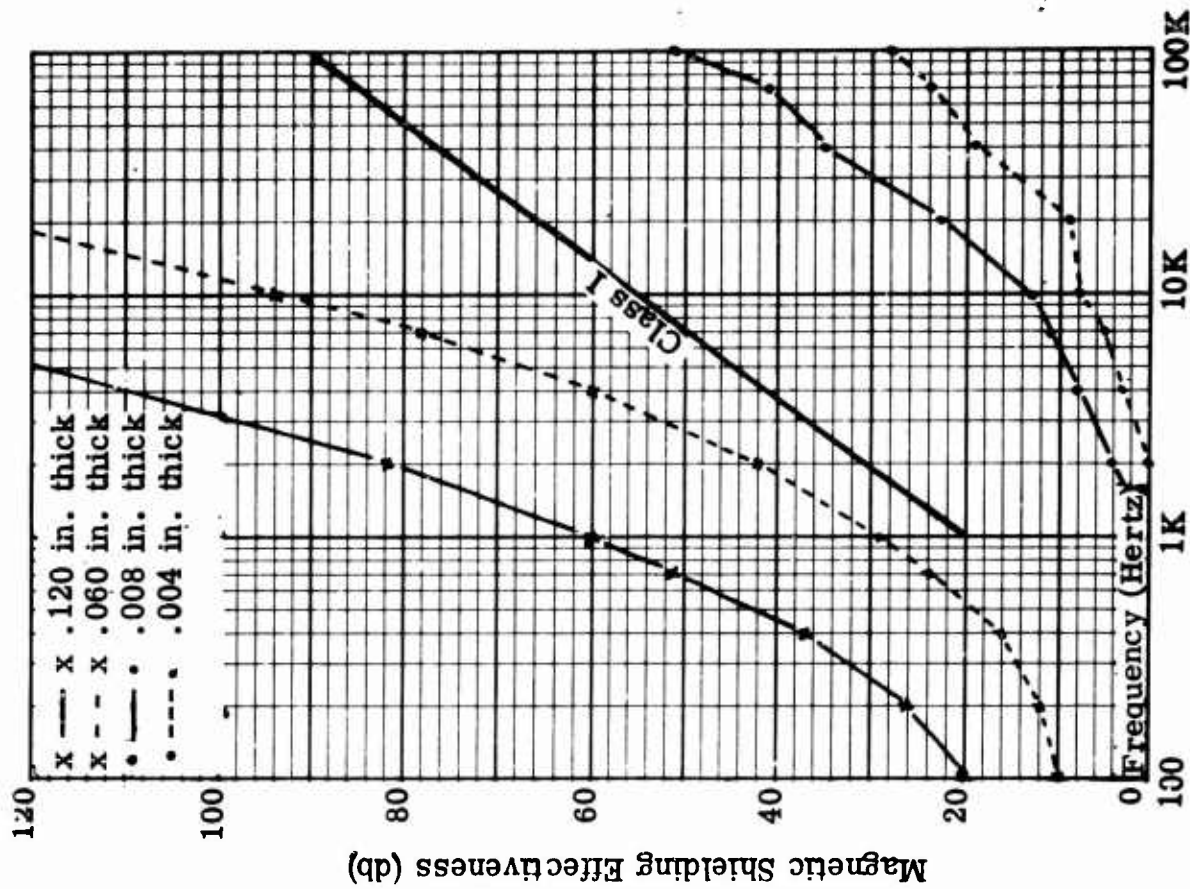


FIGURE 32 MAGNETIC SHIELDING EFFECTIVE -
NESS OF PRIMAG 40 AT TWO INCHES

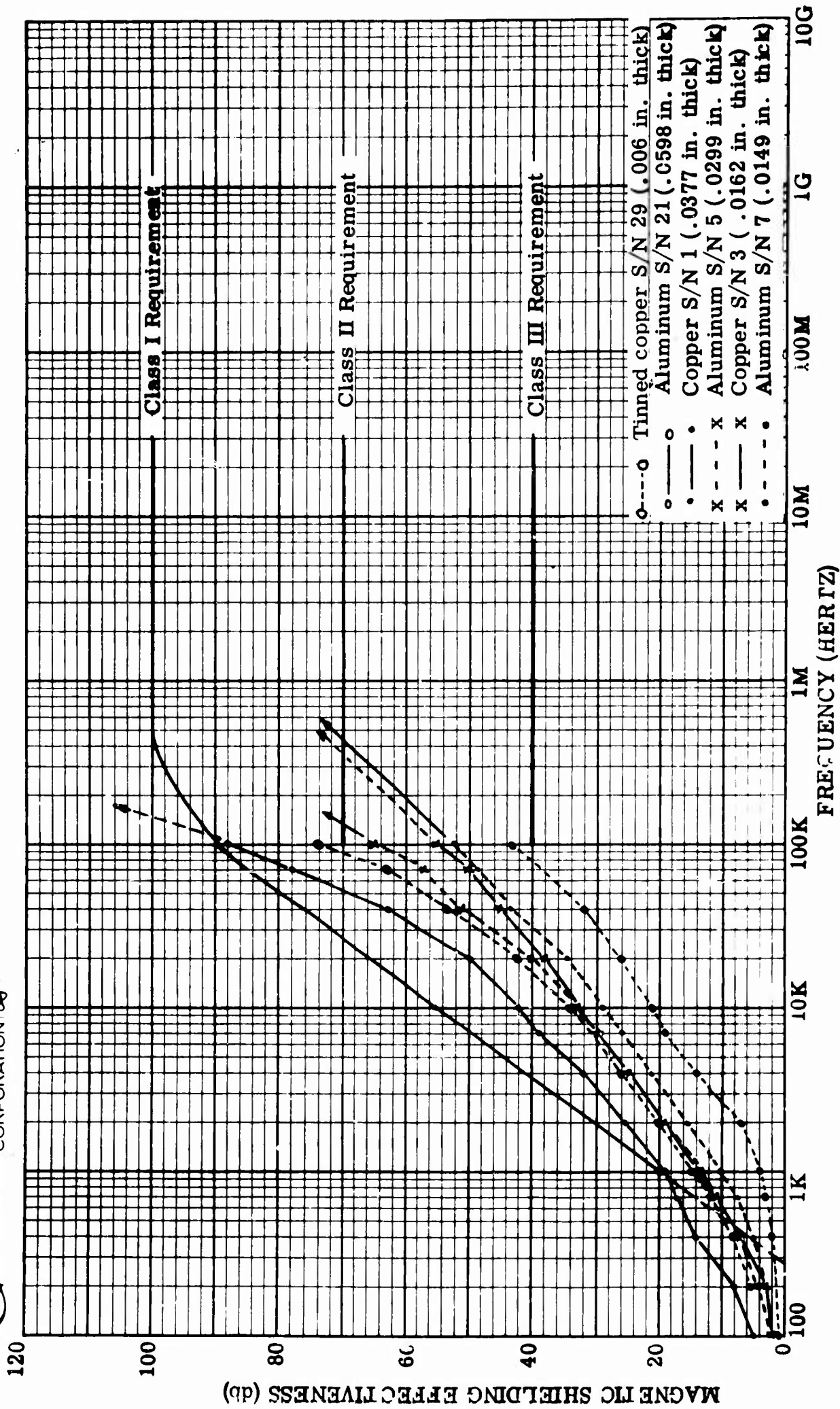


FIGURE 33 MAGNETIC SHIELDING EFFECTIVENESS OF NON-FERROUS METALS ($r = 2$ in.)

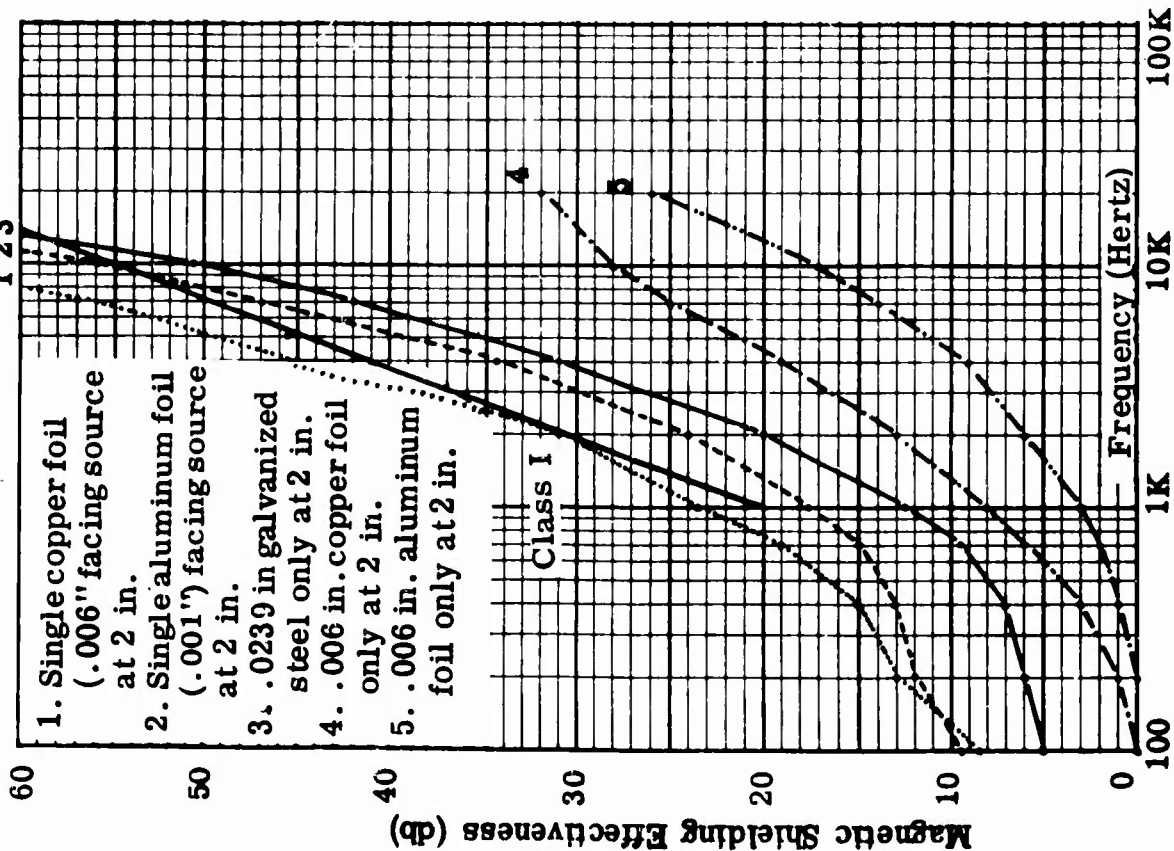


FIGURE 34 COMPOSITE MAGNETIC SHIELDING EFFECTIVENESS OF .0239 IN. GALVANIZED STEEL AND FOILS

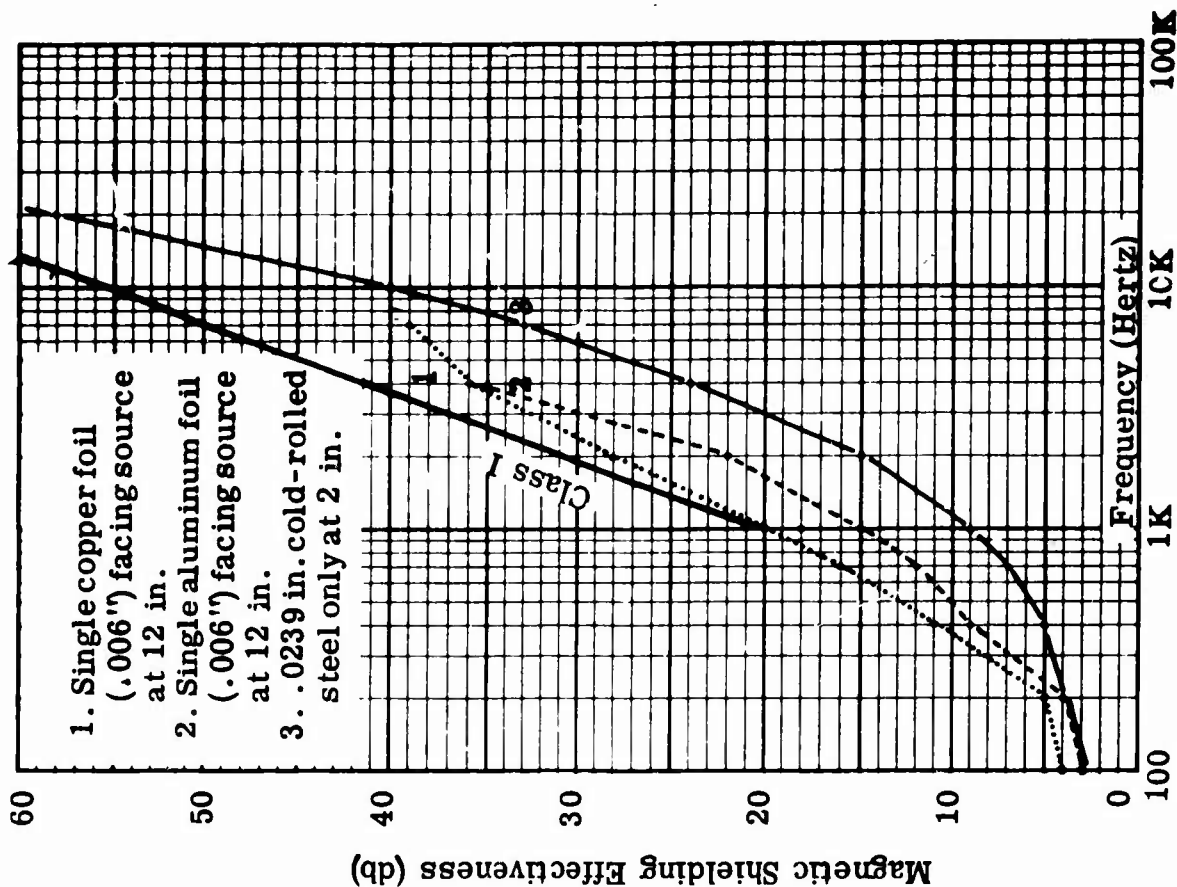


FIGURE 35 COMPOSITE MAGNETIC SHIELDING EFFECTIVENESS OF .0239 IN. COLD-ROLLED STEEL AND FOILS

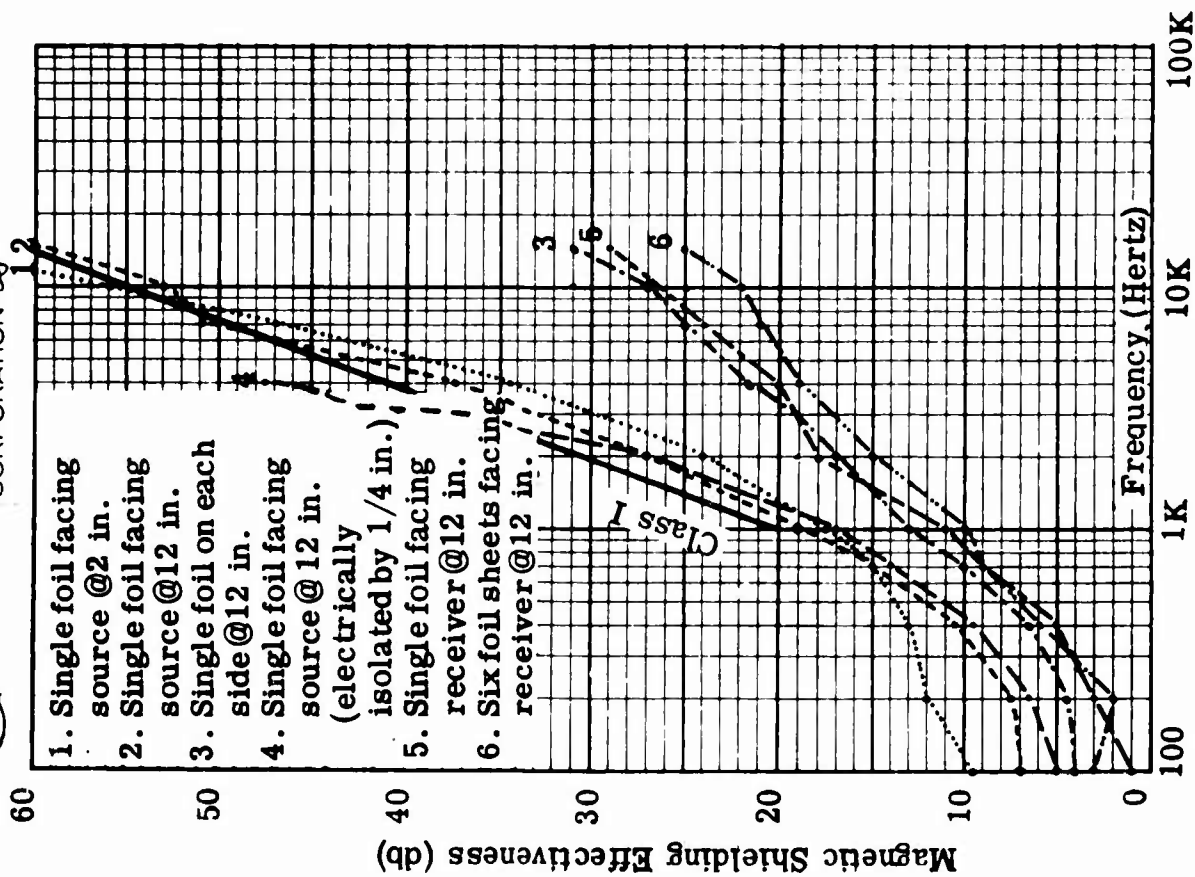


FIGURE 36 COMPOSITE MAGNETIC SHIELDING EFFECTIVENESS OF .0239 IN. GALVANIZED STEEL AND .001 IN. ALUMINUM FOIL

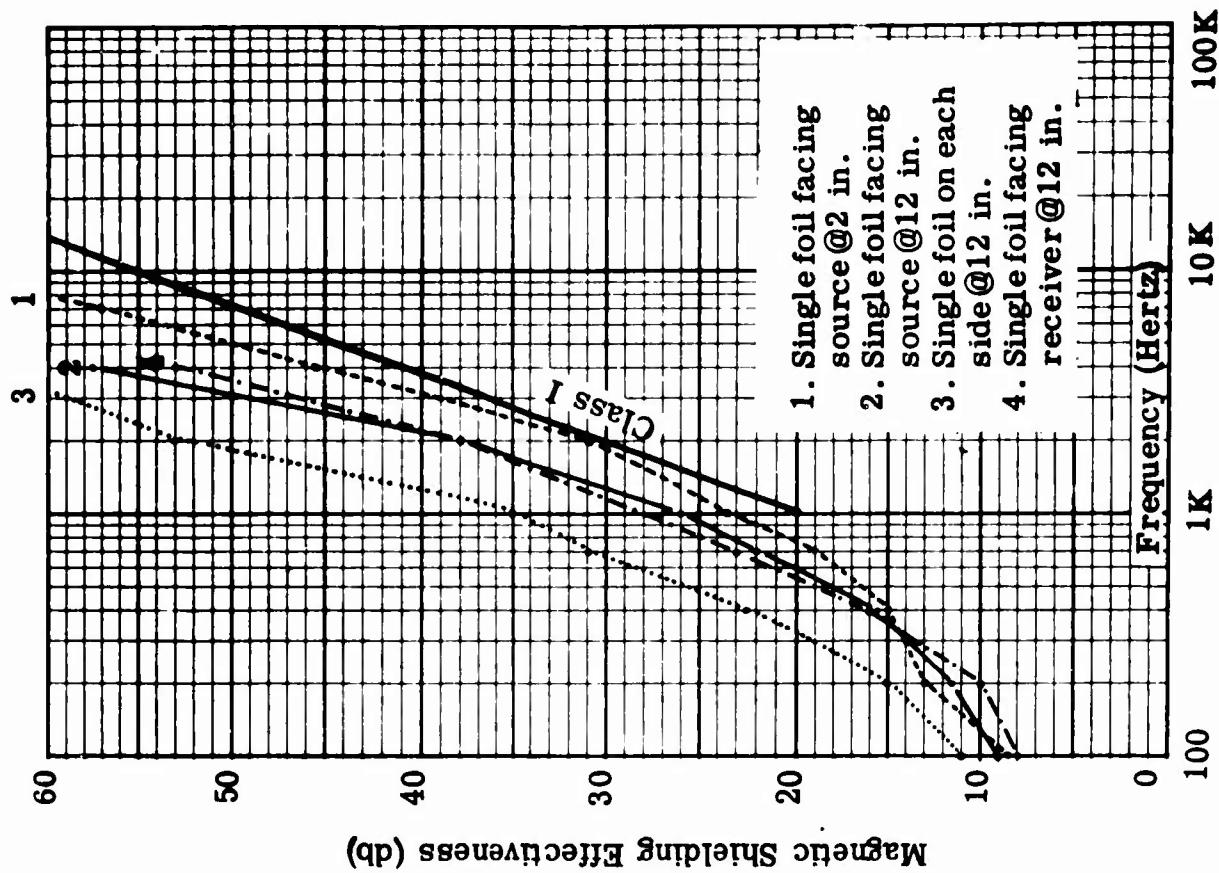


FIGURE 37 COMPOSITE MAGNETIC SHIELDING EFFECTIVENESS OF .0239 IN. GALVANIZED STEEL AND .006 IN. COPPER FOIL

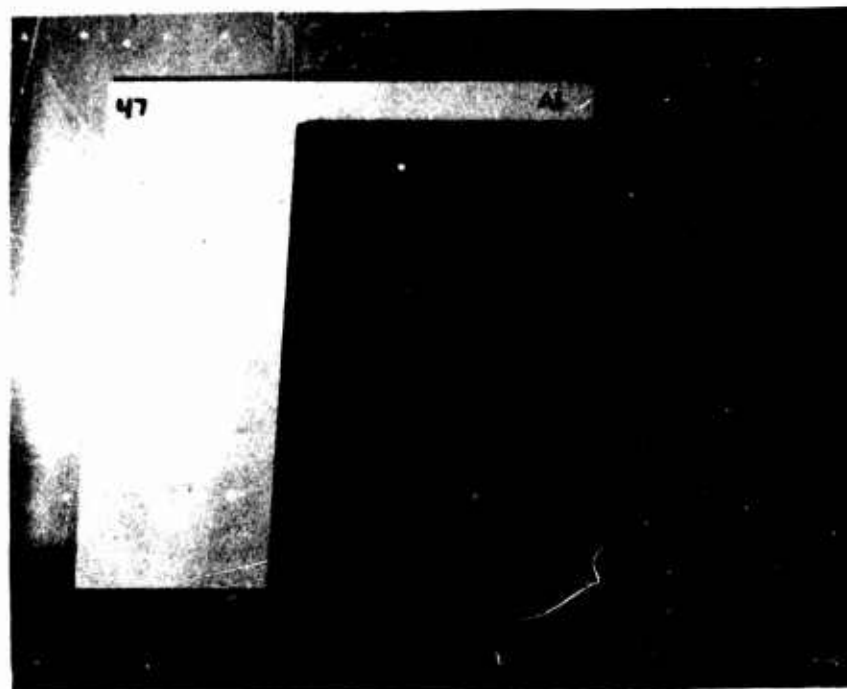


FIGURE 38 FLAME SPRAYED ALUMINUM AND STEEL

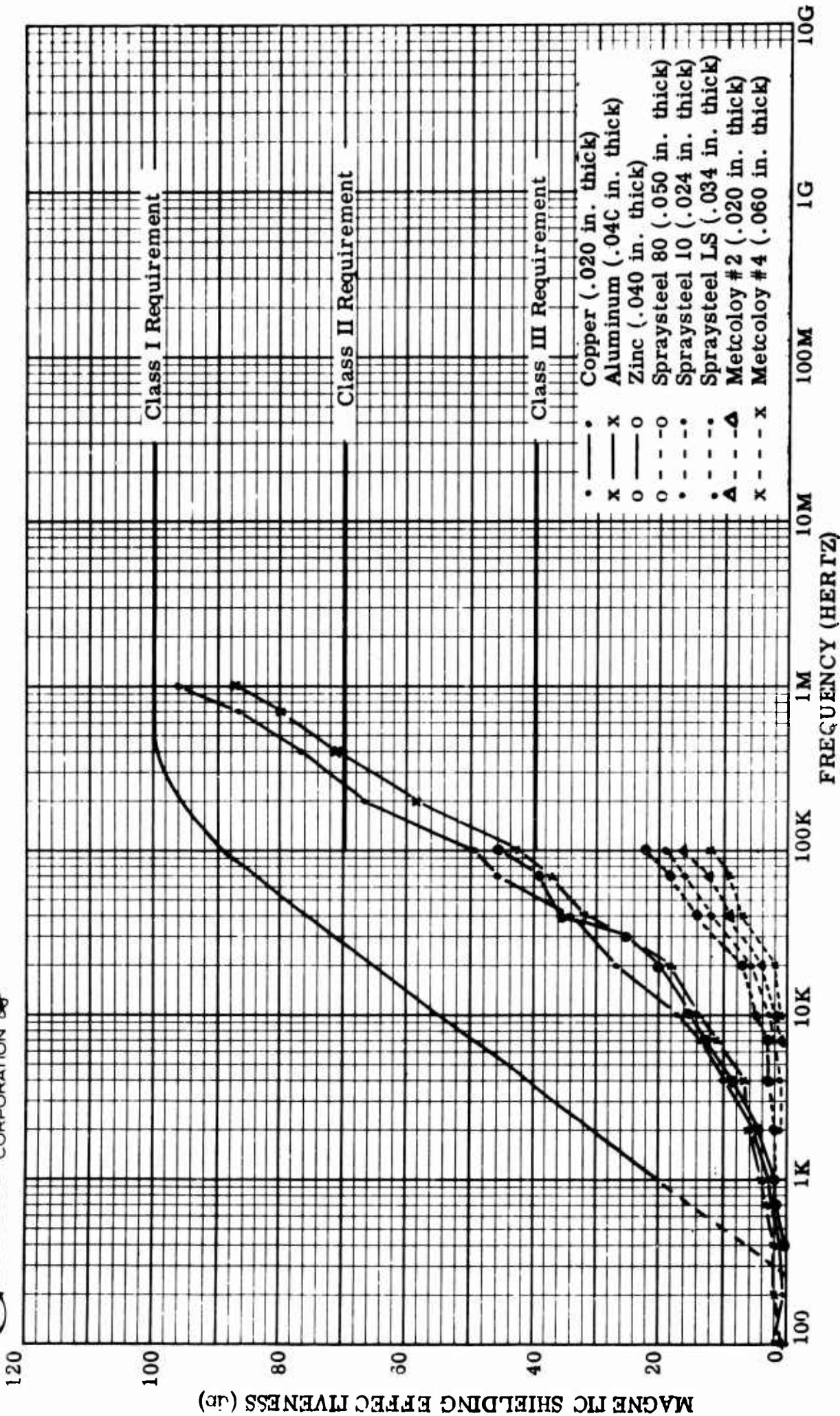


FIGURE 39 MAGNETIC SHIELDING EFFECTIVENESS OF FLAME-SPRAYED METALS ($r = 2$ in.)

Sample No. Material Type Thickness (Inches)

58 Monel wire cloth 100 mesh
 59 Monel wire cloth 200 mesh
 66 Galvanized steel screen 8 mesh
 67 Galvanized steel screen 2 mesh
 68 Aluminum screen 18 mesh
 69 Chicken wire 1 inch opening

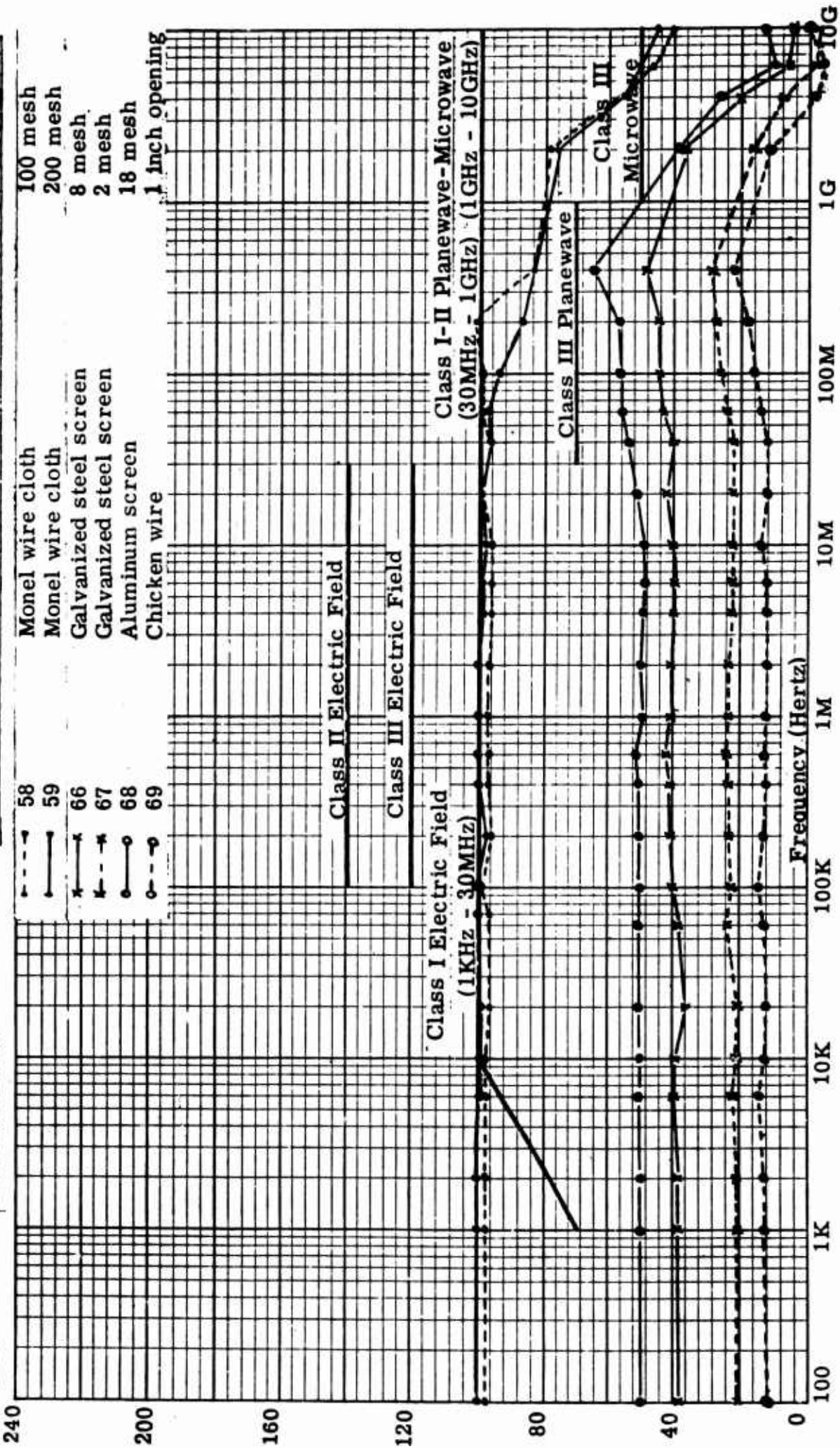


FIGURE 40 SHIELDING EFFECTIVENESS FOR ELECTRIC FIELDS, PLANEWAVES, AND MICROWAVES FOR SCREEN MATERIALS

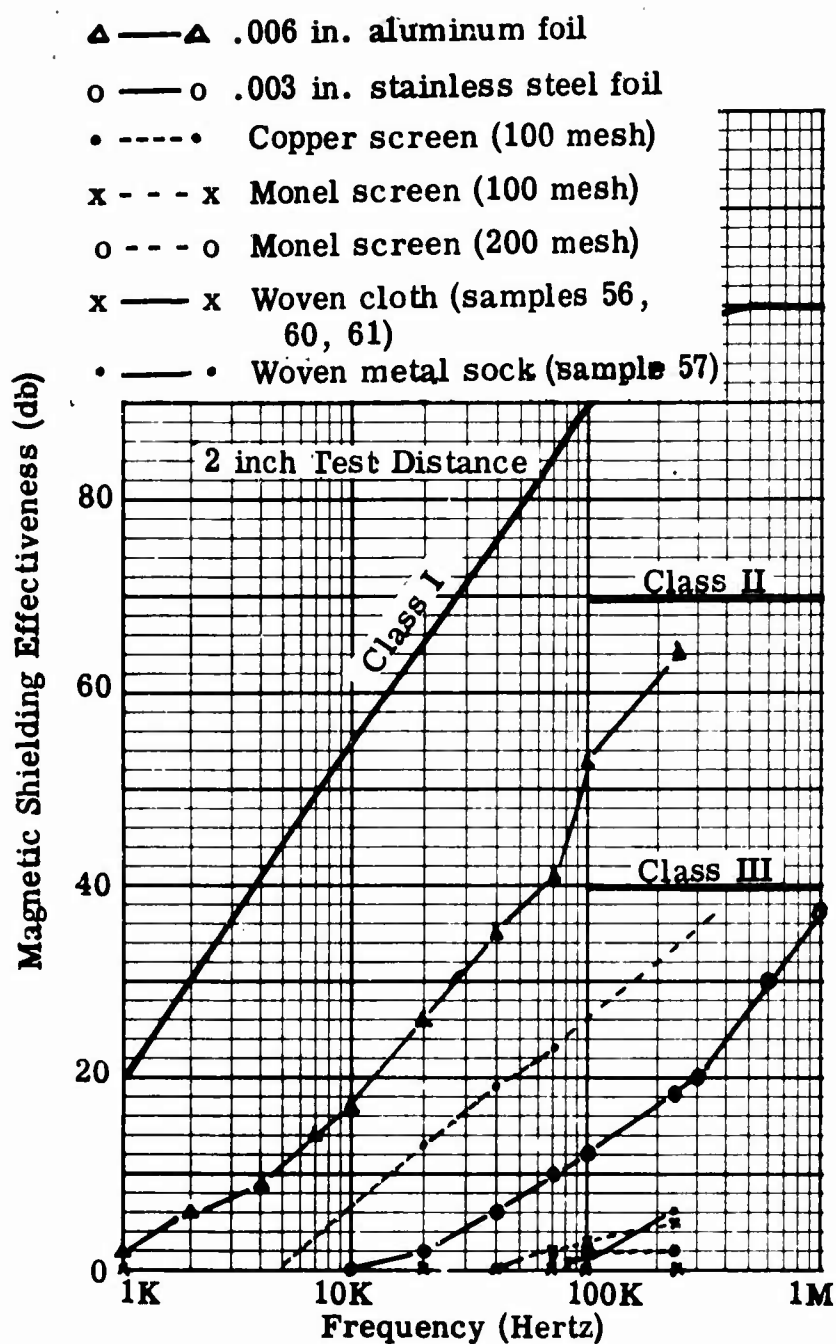


FIGURE 41 MAGNETIC SHIELDING EFFECTIVENESS OF FOILS, SCREENS AND WOVEN CLOTHS

CORPORATE 132A A.P.

Sample No.	Material Type	Thickness (Inches)
56	Marquisette (heavy) metallized woven nylon	20 strands/in.
57	Woven metal sock	18 strands/in.
60	Light rip stop metallized woven nylon	
61	Heavy rip stop metallized woven nylon	

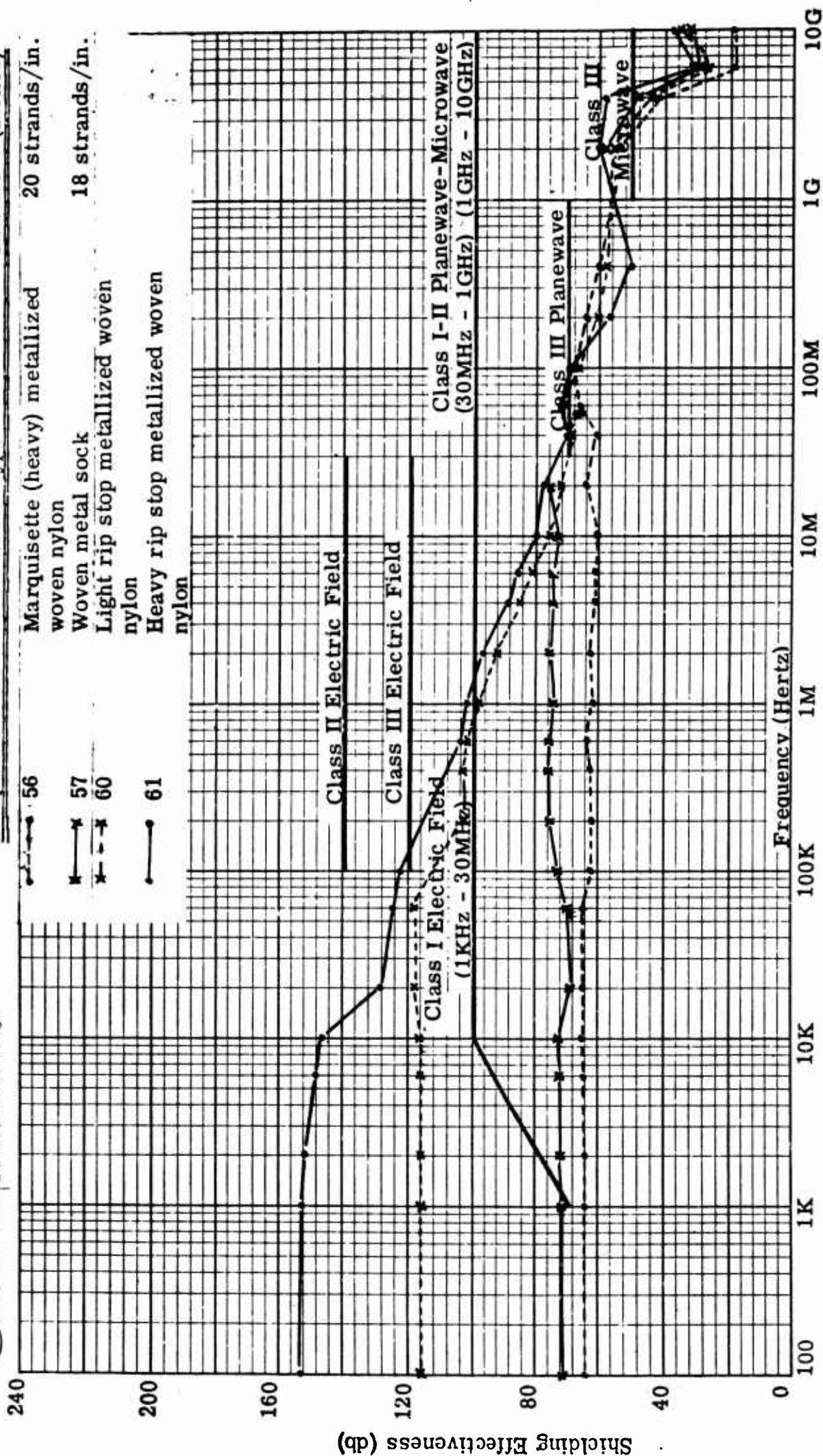


FIGURE 42 SHIELDING EFFECTIVENESS FOR ELECTRIC FIELDS, PLANEWAVES, AND MICROWAVES FOR WOVEN CLOTH SHIELDS

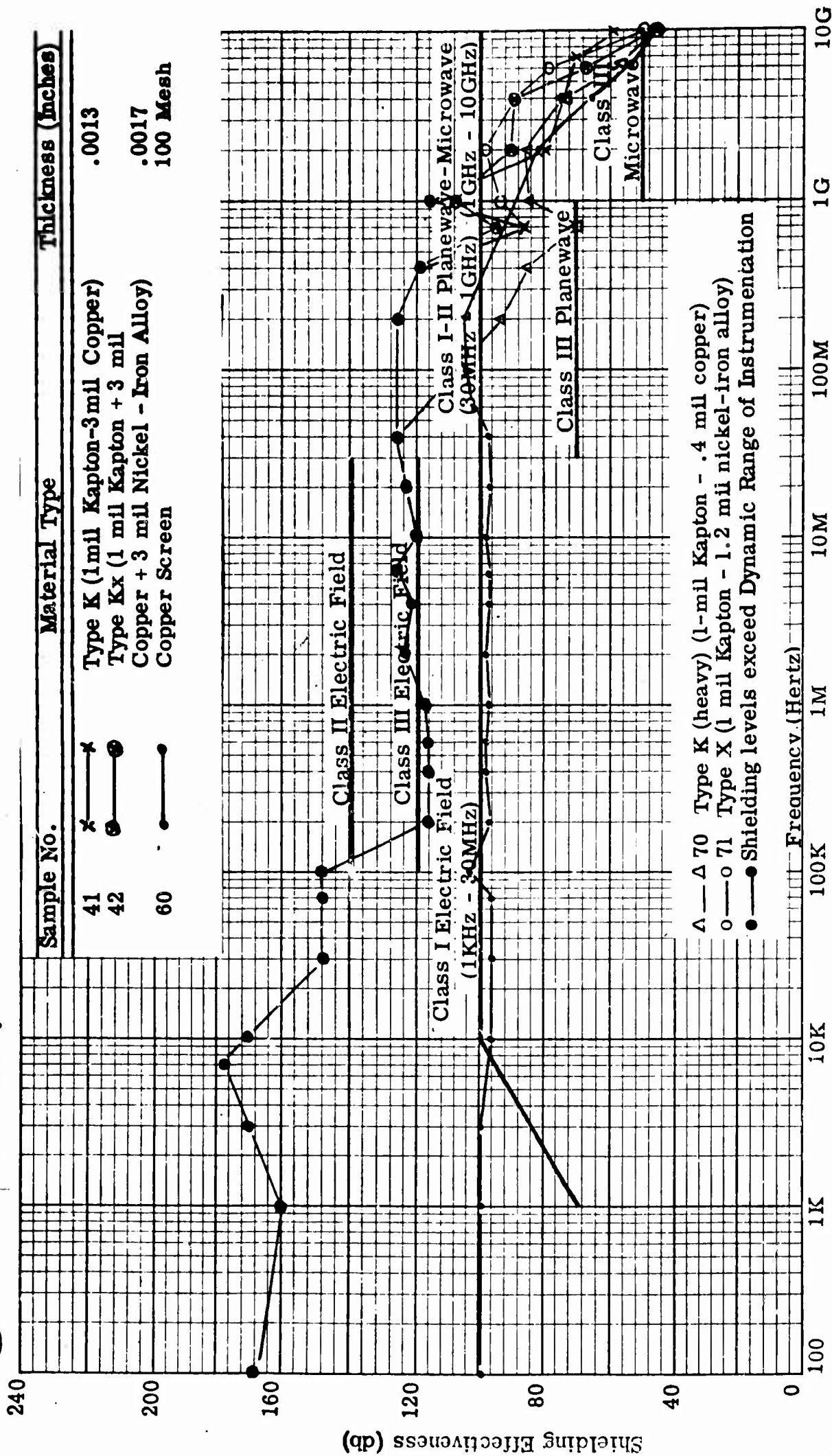


FIGURE 43 SHIELDING EFFECTIVENESS FOR ELECTRIC FIELDS, PLANEWAVES, AND MICROWAVES FOR COPPER SCREEN AND KAPTON FOILS

Sample No. Material Type Thickness (Inches)

44	Hot-rolled steel	.077
45	Hot-rolled steel	.077
46	Flame-sprayed copper	.020
47	Flame-sprayed aluminum	.040
48	Flame-sprayed zinc	.040
49	Flame-sprayed spray steel LS	.034
50	Flame-sprayed spray steel 80	.050
51	Flame-sprayed spray steel 10	.024
52	Flame-sprayed metcoloy #2	.020
53	Flame-sprayed metcoloy #4	.060
71	1-mil kapton -1.2 mil nickel-iron alloy type X	.0022

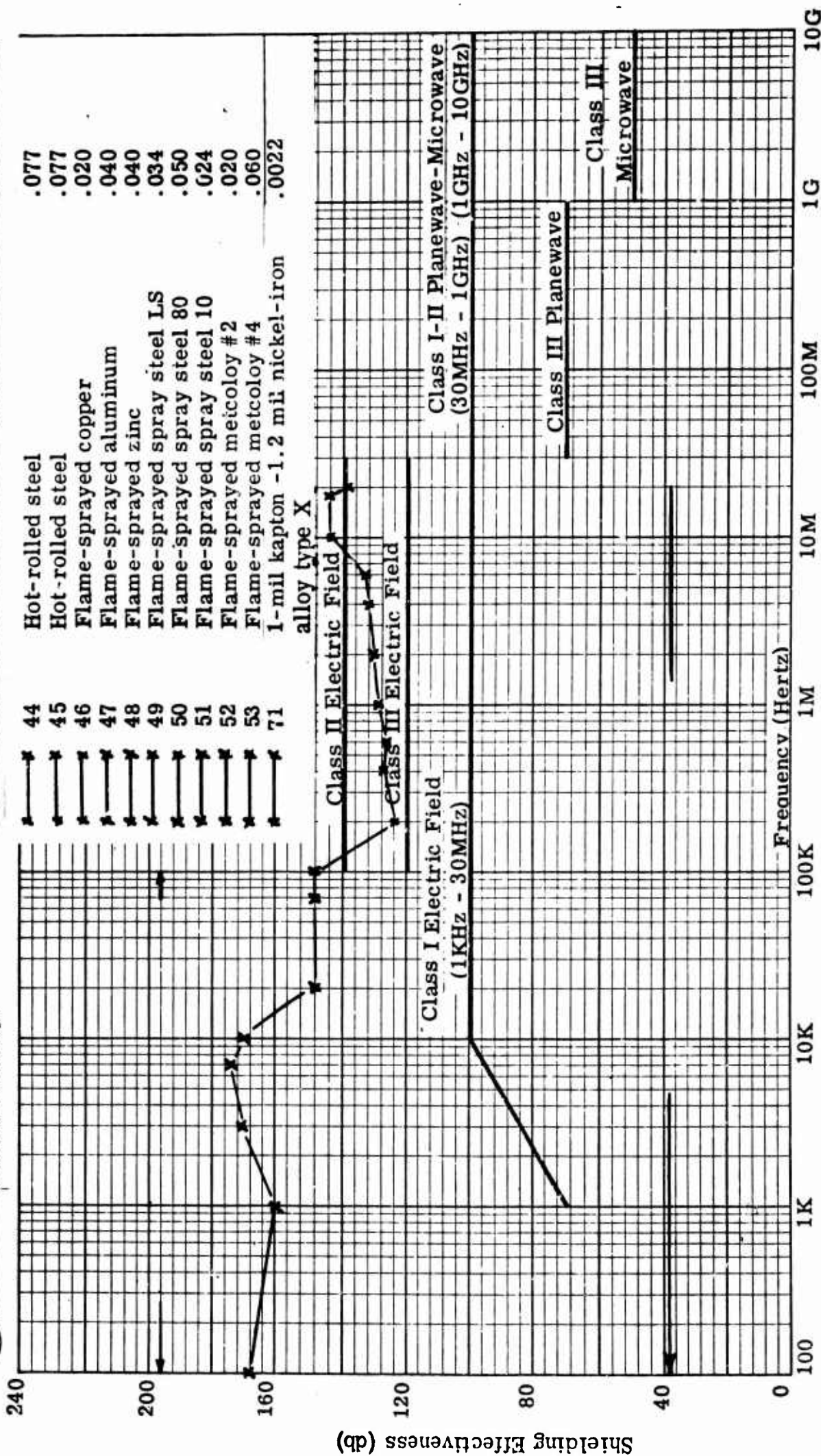


FIGURE 44 SHIELDING EFFECTIVENESS FOR ELECTRIC FIELDS, PLANEWAVES, AND MICROWAVES FOR FLAME SPRAYED MATERIALS AND KAPTON FOIL

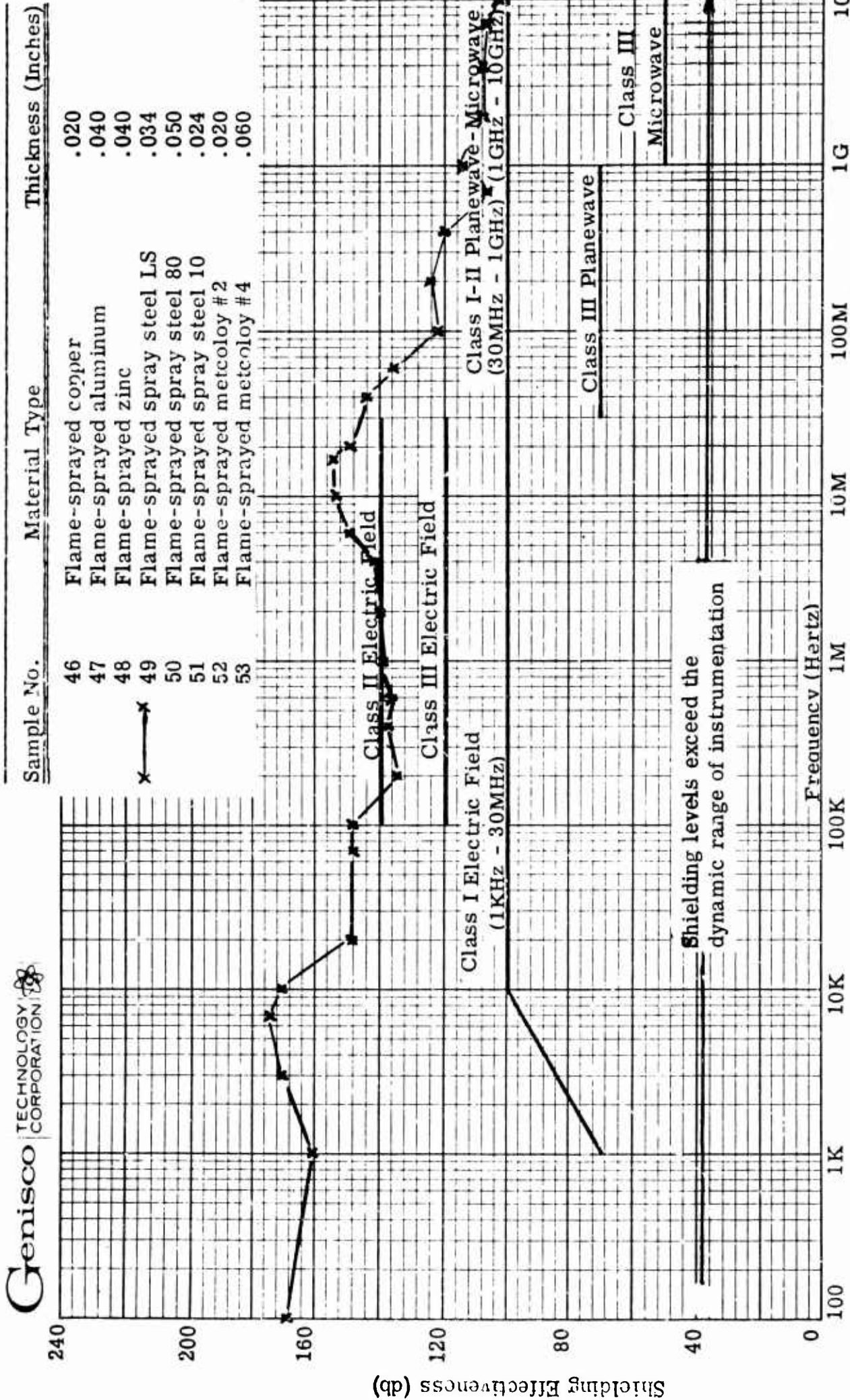


FIGURE 45 SHIELDING EFFECTIVENESS FOR ELECTRIC FIELDS, PLANEWAVES, AND MICROWAVES FOR FLAME SPRAYED MATERIALS

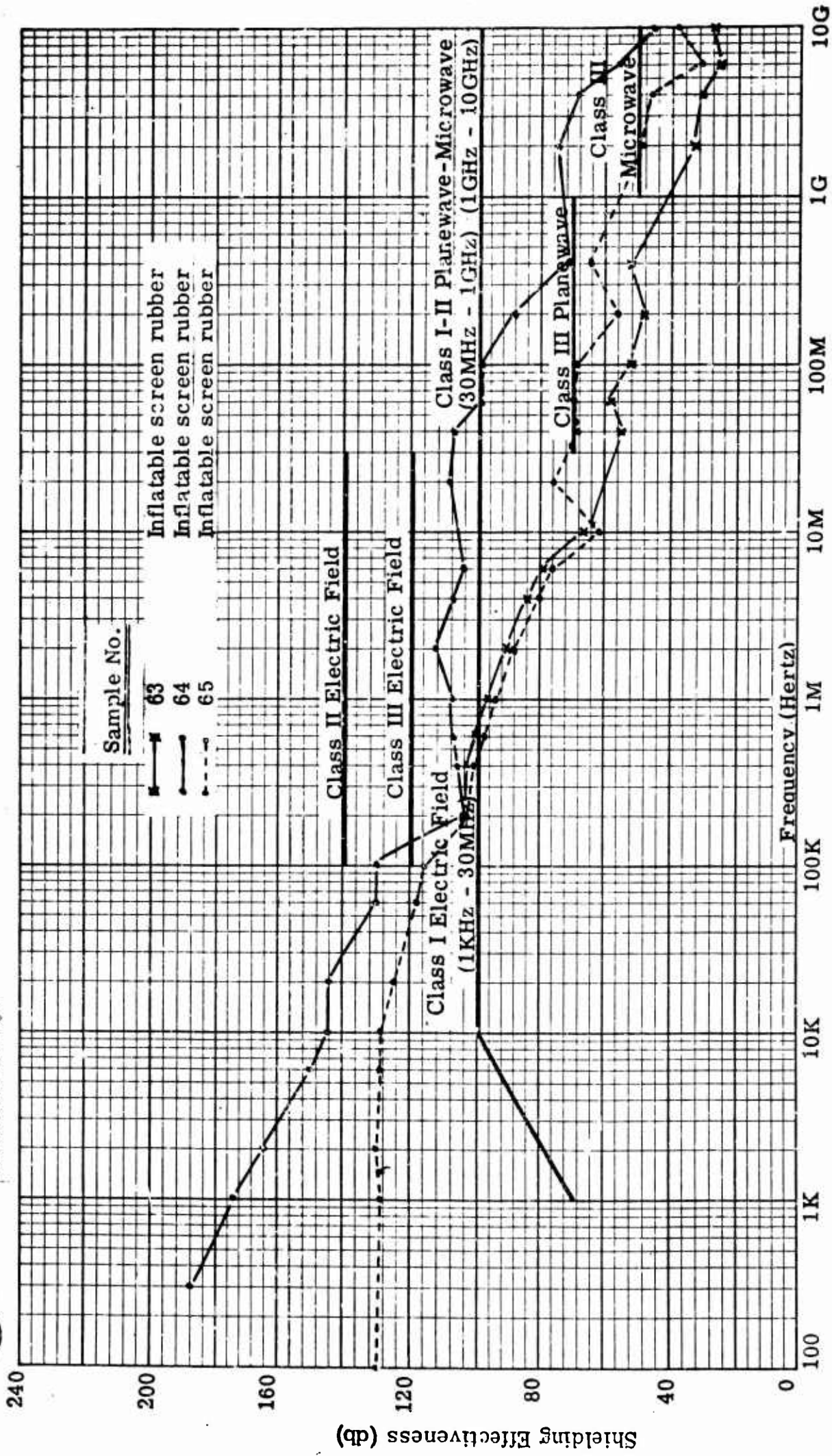
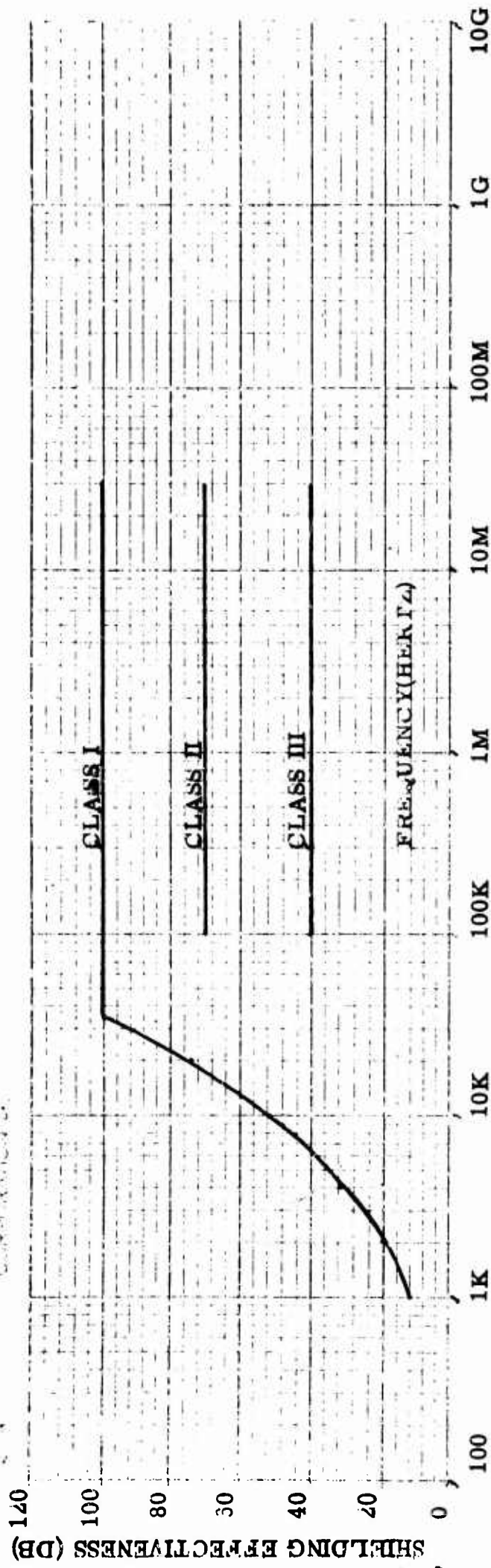
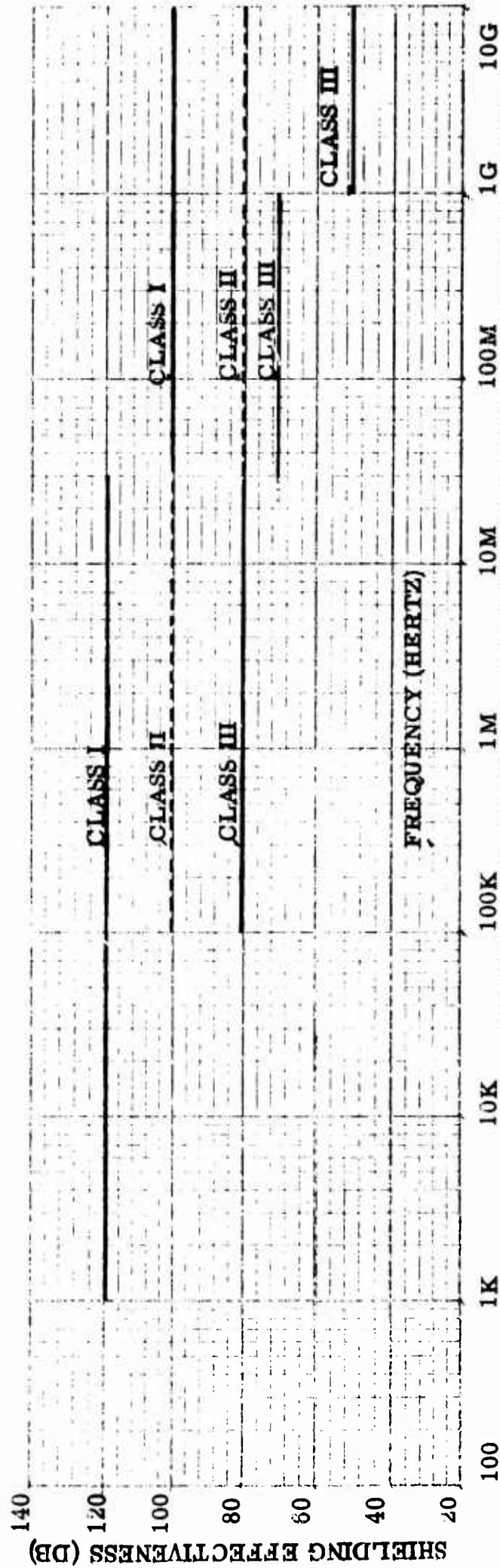


FIGURE 4b SHIELDING EFFECTIVENESS FOR ELECTRIC FIELDS, PLANEWAVES, AND MICROWAVES FOR INFLATABLE RUBBER SHIELDS

STANDARD, CORP. 1965 3A



MAGNETIC SHIELDING REQUIREMENTS



ELECTRIC, PLANE WAVE, AND MICROWAVE SHIELDING REQUIREMENTS
FIGURE 47 SUGGESTED LIMITS FOR CLASS I, II, AND III ENCLOSURES

FIGURE 48 SIMULATED PERMANENT SEAMS FOR LABORATORY TESTING

Sample No.	Type Seam
77	Open Butt Seam (1/16" x 9")
78	Soldered Butt Seam
79	Copper Taped Butt Seam
80	Zinc Flame Sprayed Butt Seam
81	Copper Flame Sprayed Butt Seam
82	TIG Welded Butt Seam
83	MIG Welded Butt Seam
84	Silver Soldered Butt Seam
85	Open One Inch Overlap Seam
86	Soldered One Inch Overlap Seam
87	Copper Taped One Inch Overlap Seam
88	Zinc Flame Sprayed One Inch Overlap Seam
89	Copper Flame Sprayed One Inch Overlap Seam
90	TIG Welded One Inch Overlap Seam
91	MIG Welded One Inch Overlap Seam
92	Silver Soldered One Inch Overlap Seam

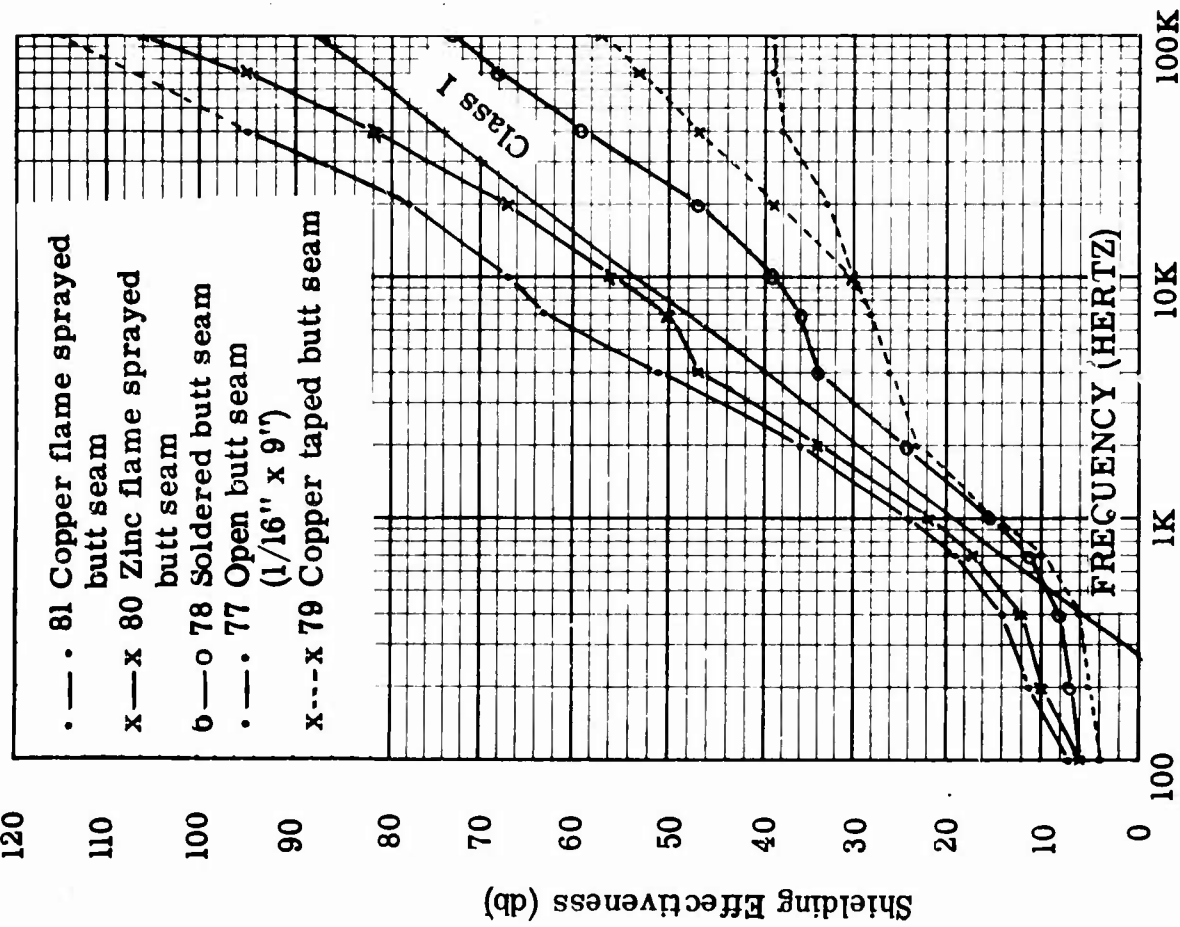


FIGURE 49

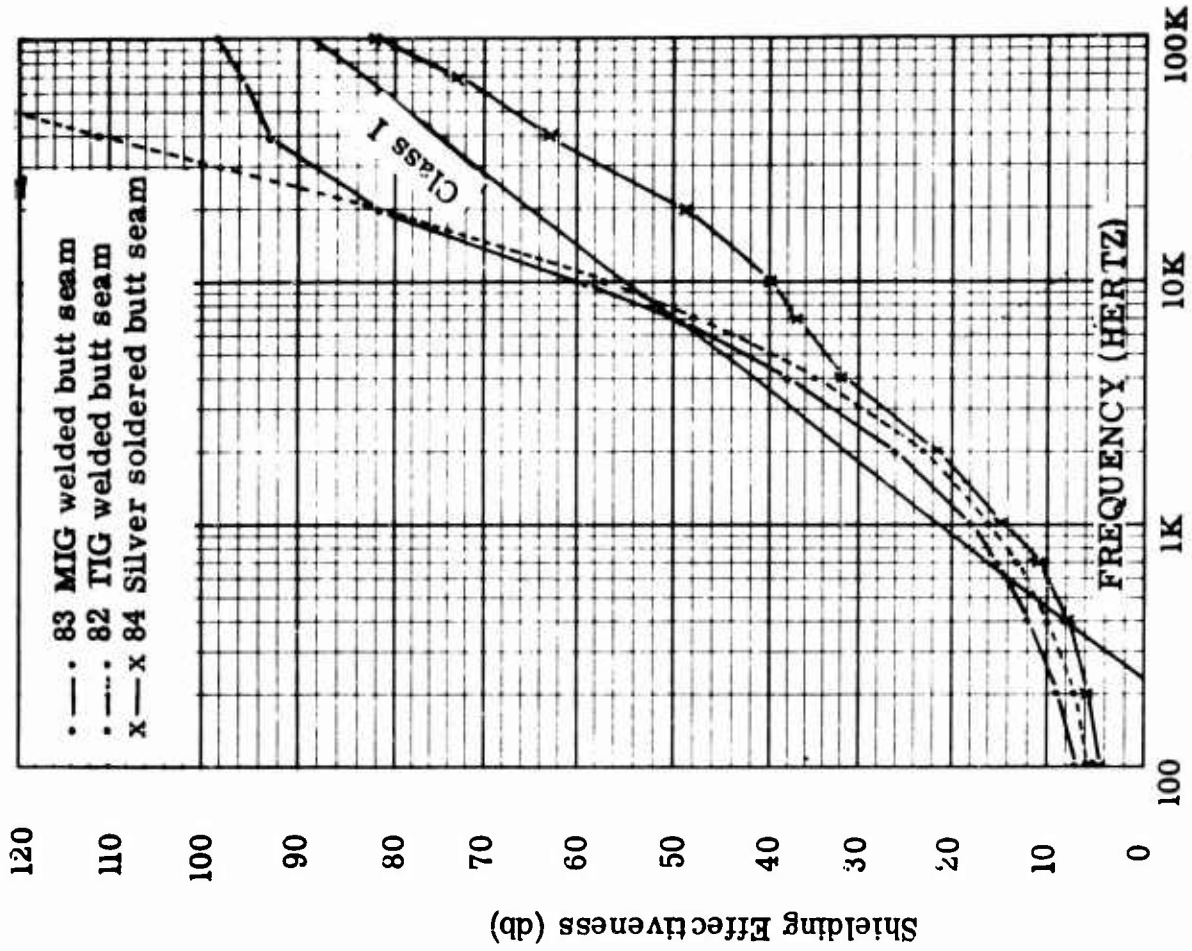


FIGURE 50

MAGNETIC SHIELDING EFFECTIVENESS OF PERMANENT BUTT SEAMS TESTED AT TWO INCHES

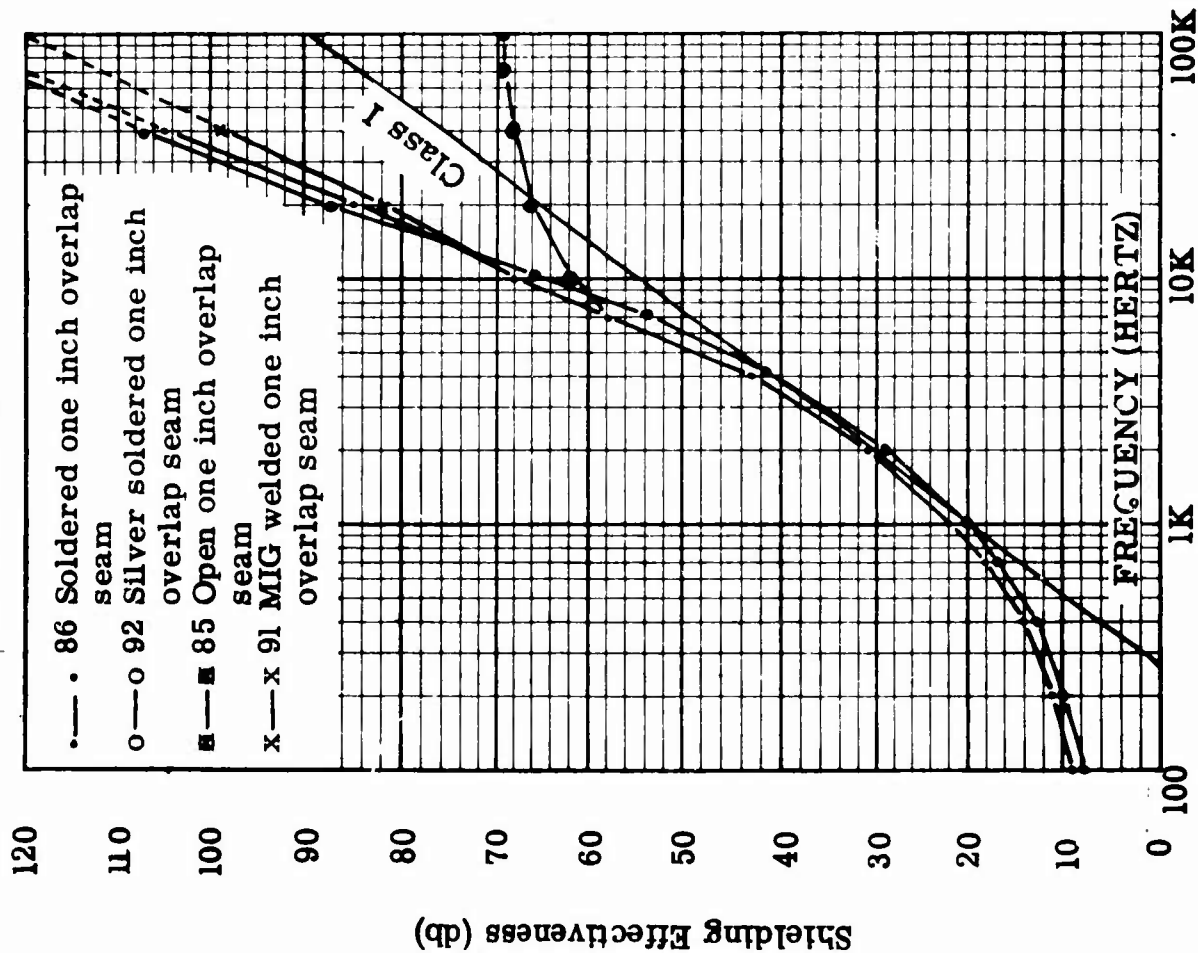


FIGURE 51

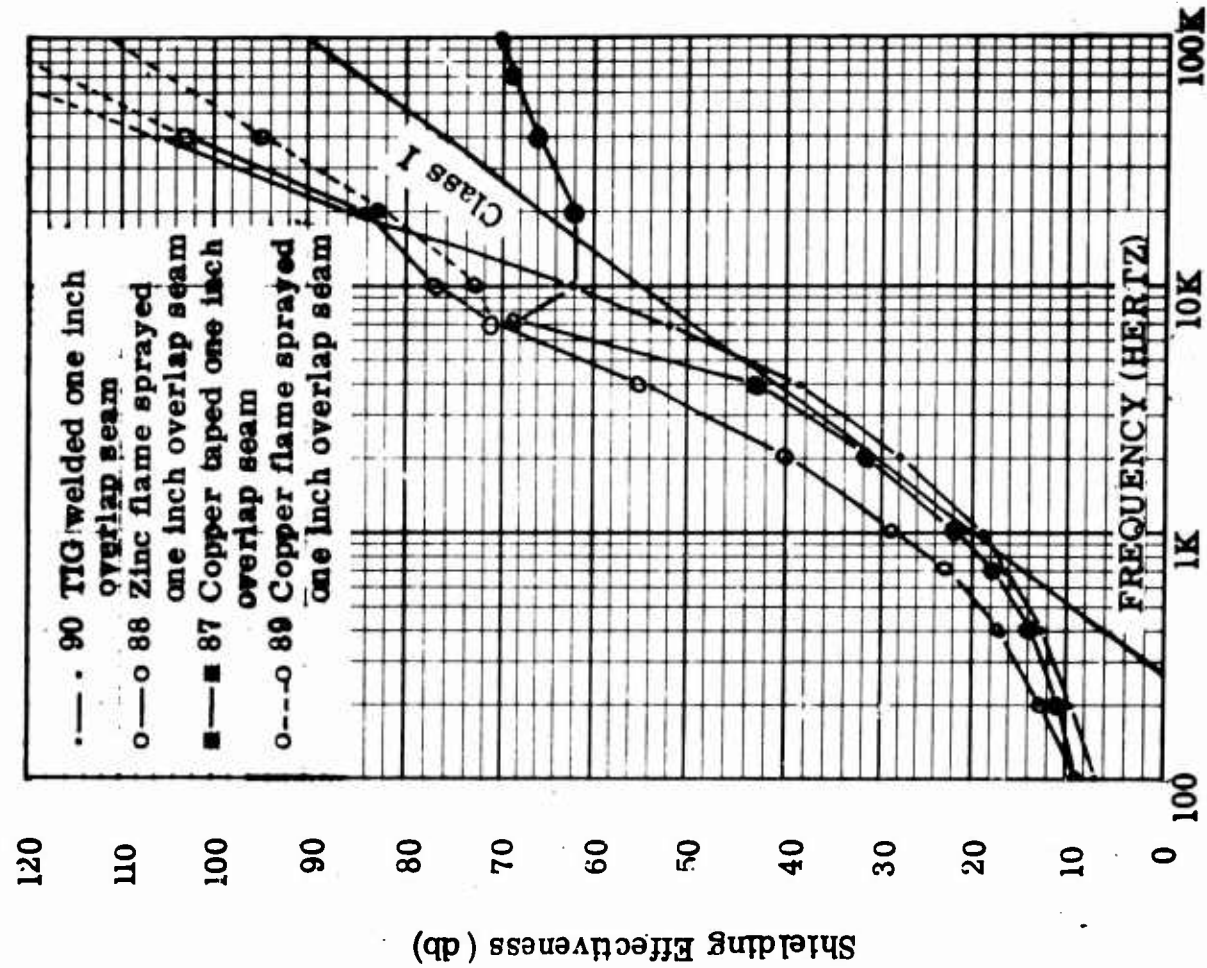


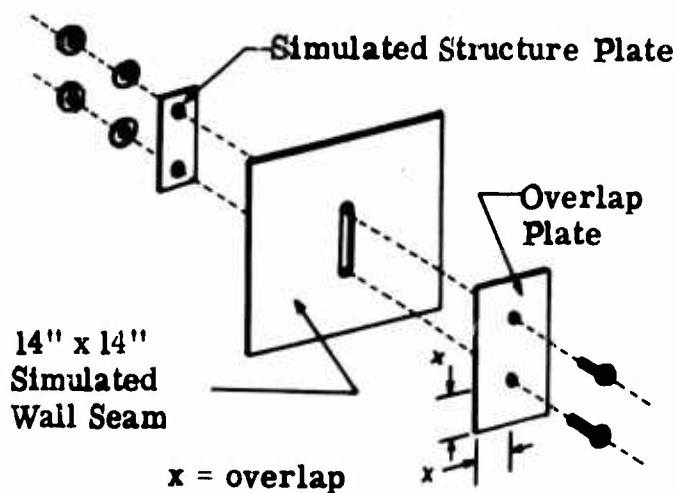
FIGURE 52

MAGNETIC SHIELDING EFFECTIVENESS OF PERMANENT OVERLAP SEAMS TESTED AT TWO INCHES

Figure 83 Simulated Overlap Seams for Portable Enclosures

Sample No.	Type Seam
93	Simulated wall seam (14" x 14") with an open 5/16" x 4" slot of 18 gage galvanized steel
94	1/2" overlap
95	1" overlap
96	2" overlap
97	1/2" overlap with simulated structure plate (metal)
98	1" overlap with simulated structure plate (metal)
99	2" overlap with simulated structure plate (metal)
100	1/2" overlap with simulated structure plate (wood)

Samples 94 - 100 are simulated bolt-together seams with a 4" bolt spacing. The overlap plates are 14 gage galvanized steel. In laboratory testing the overlap plates are used in conjunction with the simulated wall seam (93) and optionally with a simulated structure plate as shown below:



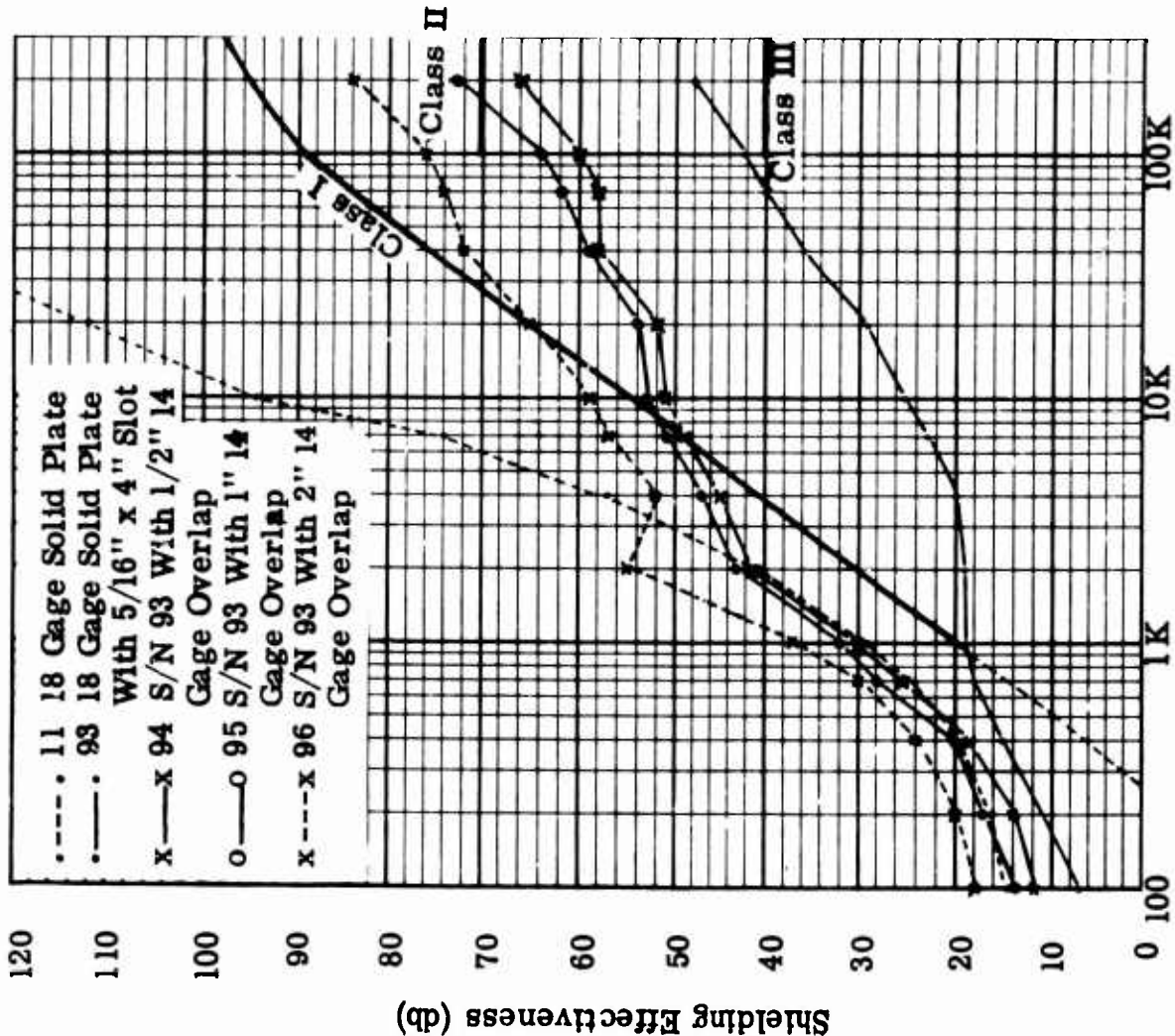


FIGURE 54 MAGNETIC SHIELDING EFFECTIVENESS OF GALVANIZED STEEL OVERLAP SEAMS WITHOUT SIMULATED STRUCTURE

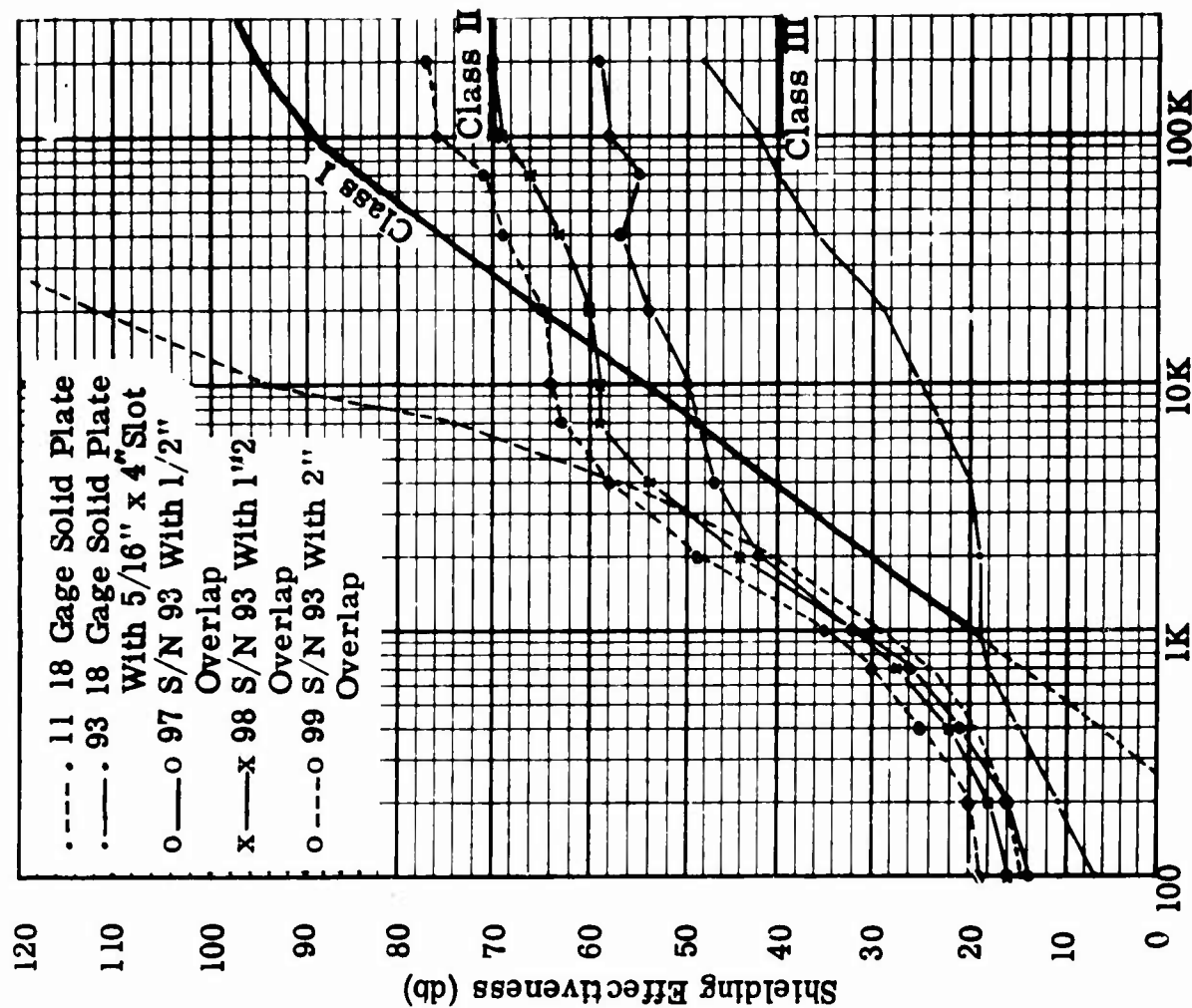


FIGURE 55 MAGNETIC EFFECTIVENESS OF GALVANIZED STEEL OVERLAP SEAMS WITH SIMULATED METAL STRUCTURE

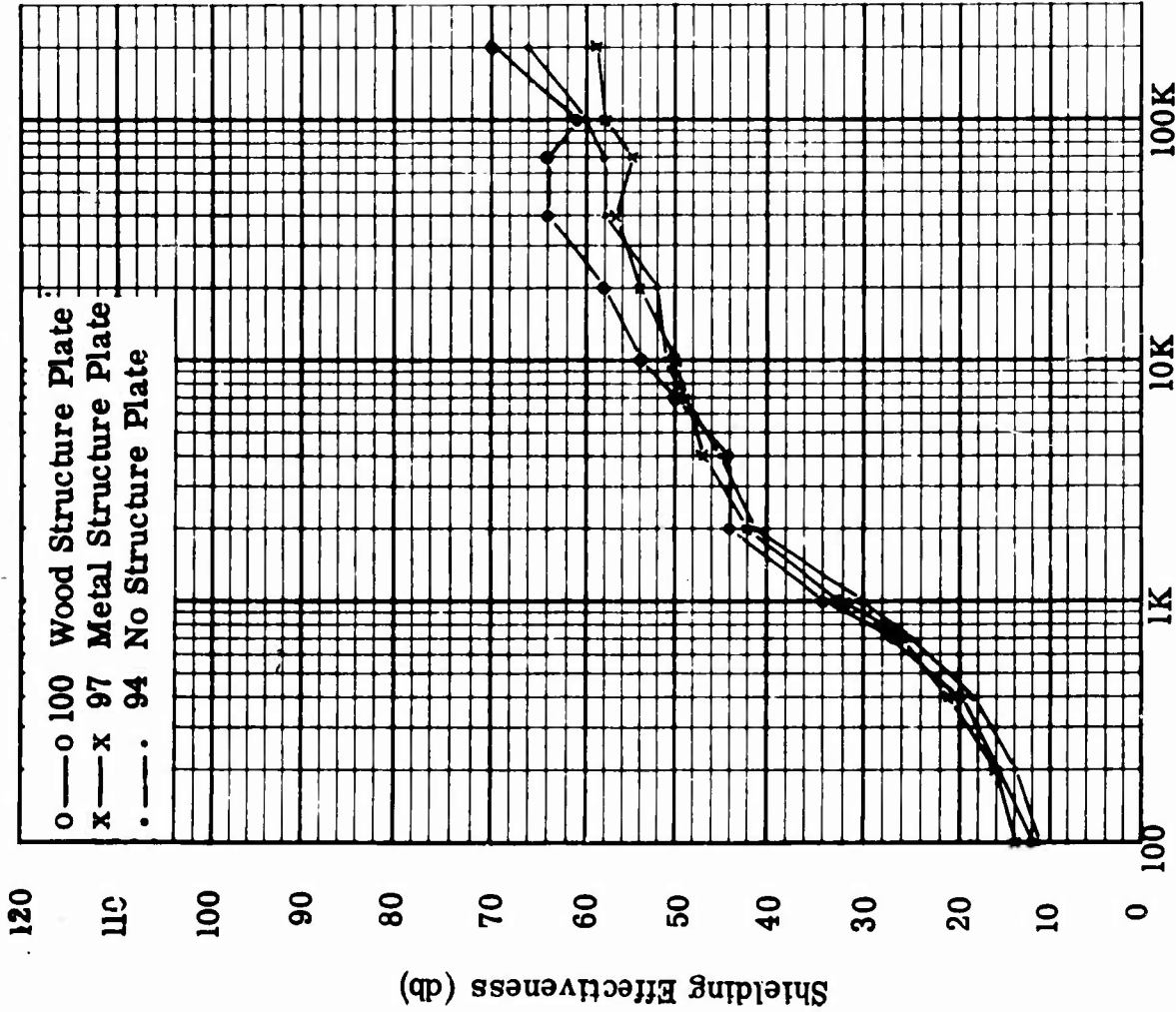


FIGURE 56 COMPARISON OF MAGNETIC SHIELDING EFFECTIVENESS FOR VARIOUS SIMULATED STRUCTURE PLATES WITH A HALF INCH OVERLAP SEAM

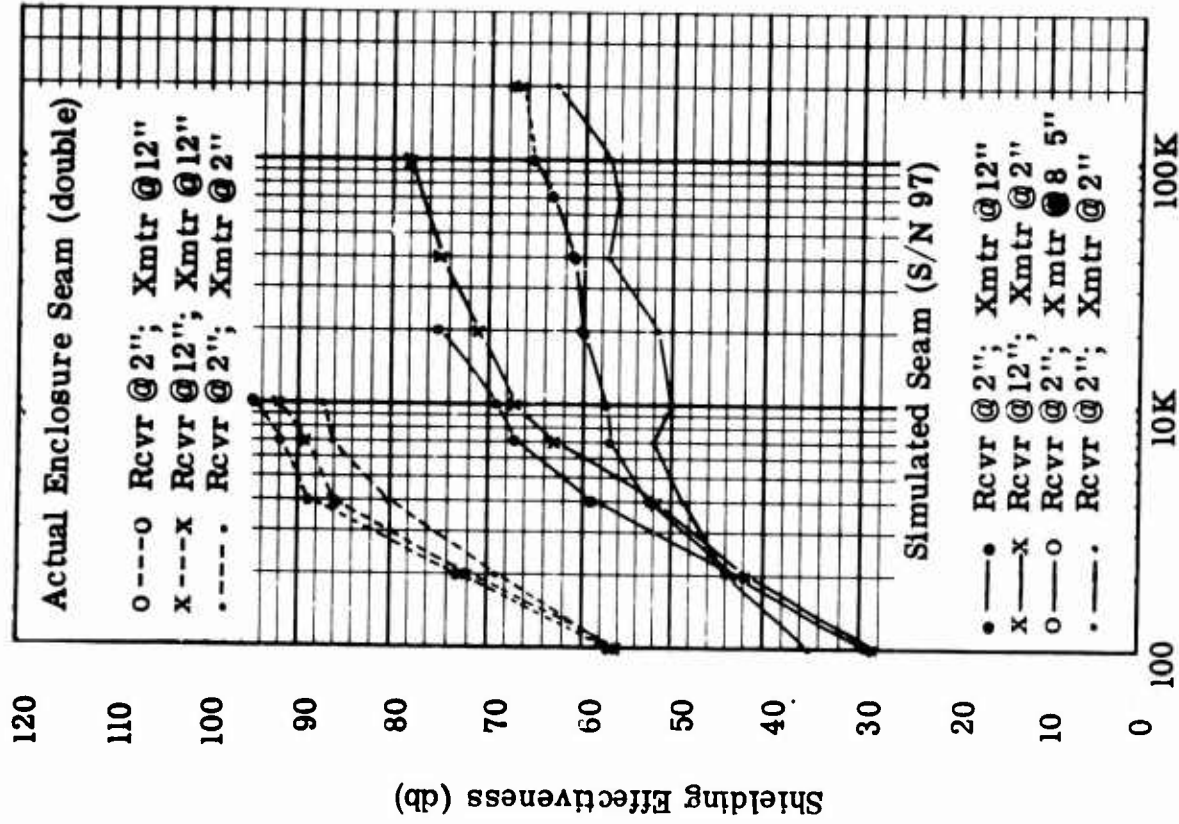


FIGURE 57 MAGNETIC SHIELDING EFFECTIVENESS OF A SIMULATED AND ACTUAL OVERLAP SEAM AT VARIOUS TEST DISTANCES

FIGURE 58

ITEMS TO TEST PER ENCLOSURE

PORTABLE ENCLOSURES AND PERMANENT ENCLOSURES:

- 1. filter panel
- 2. door seam and handle
- 3. air ventilators
- 4. corner seams
- 5. wallseam

FREQUENCY:

<u>Magnetic</u>	<u>Electric</u>	<u>Planewave</u>	<u>Microwave</u>
100Hz	100Hz	100MHz	10GHz
1KHz	1KHz	1GHz	
10KHz	10KHz		
100KHz	100KHz		
10MHz	10MHz		

TEST DISTANCE:

Magnetic: 2 inches, and 12 inches.

Electric: 24 inches plus wall thickness.

Planewave: Transmitting antenna greater than two wavelengths.

Receiving antenna 2 - 8" from the outer wall for maximum indication. This is the reference.

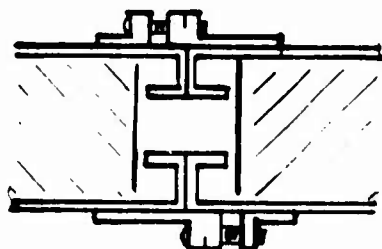
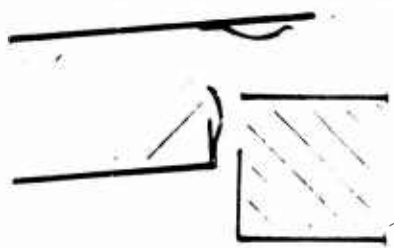
Receiving antenna inside and search for maximum indication for attenuation. Minimum test distance two inches.

Microwave: Transmitting antenna greater than two wavelengths.

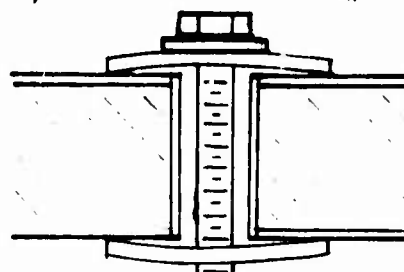
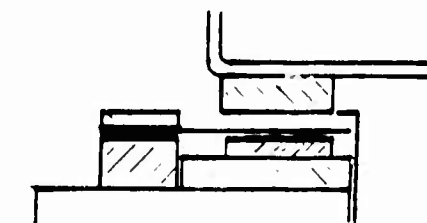
Receiving antenna set opposite transmitting antenna for maximum indication. This is the reference.

Receiving antenna inside and search wall area covered by the transmitting signal. Minimum test distance two inches.

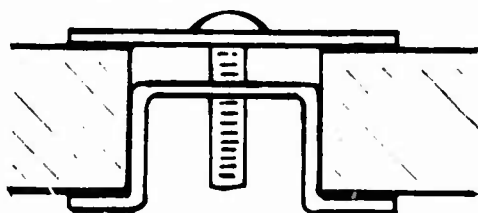
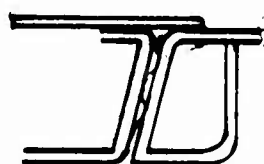
FIGURE 59
DOOR AND WALL SEAM TYPES TESTED



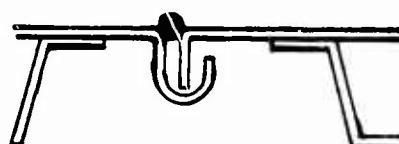
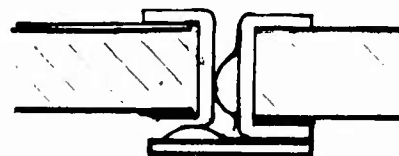
TYPE 1



TYPE 2



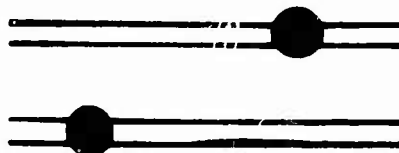
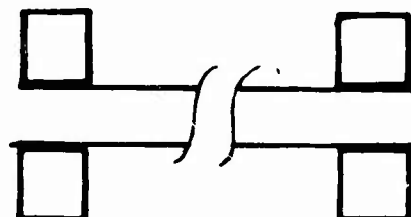
TYPE 3



TYPE 4



TYPE 5



TYPE 6

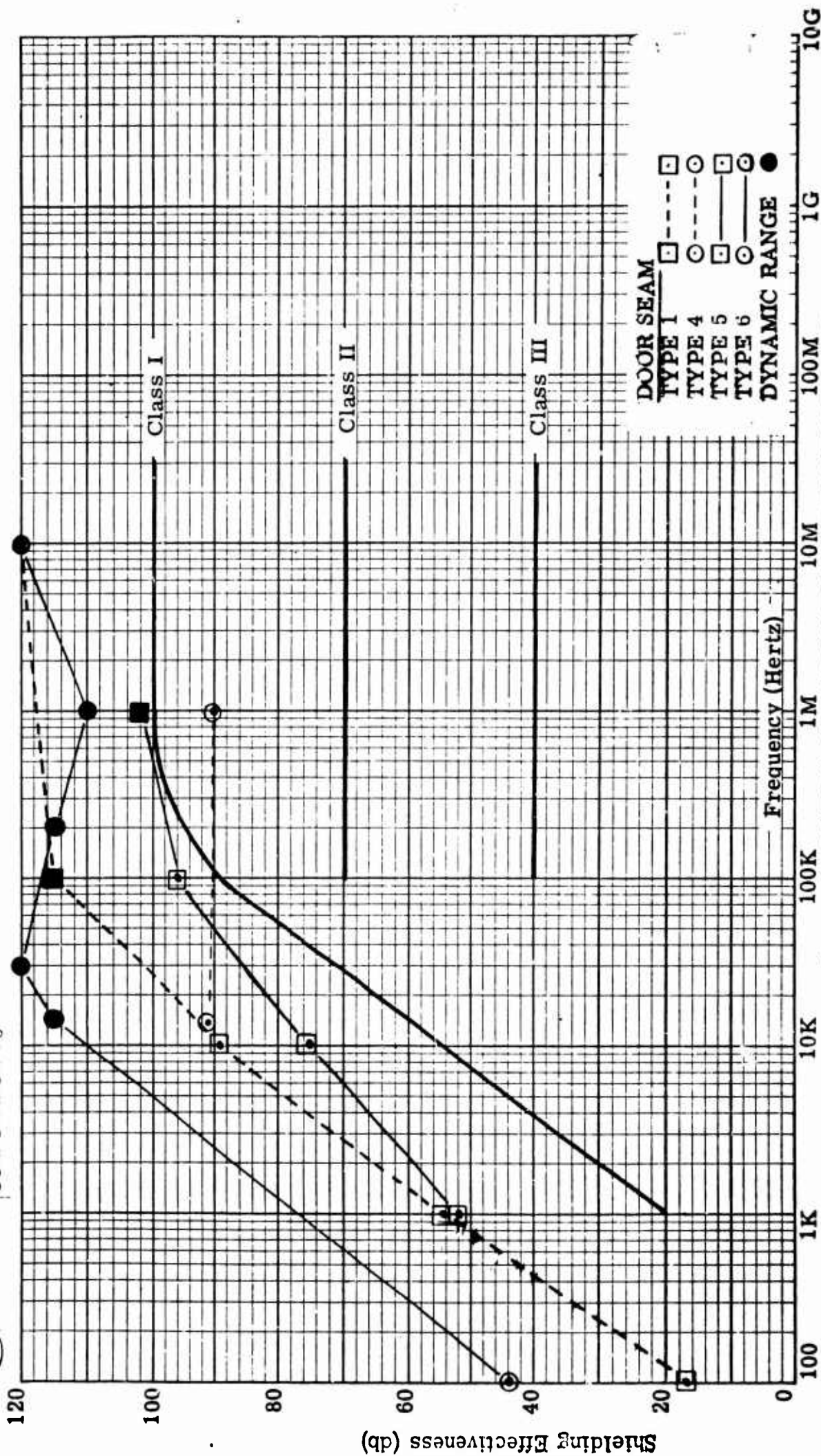


FIGURE 60 MAGNETIC SHIELDING EFFECTIVENESS FOR IN SITU SEAM TESTING OF NEW SHIELDED FACILITIES

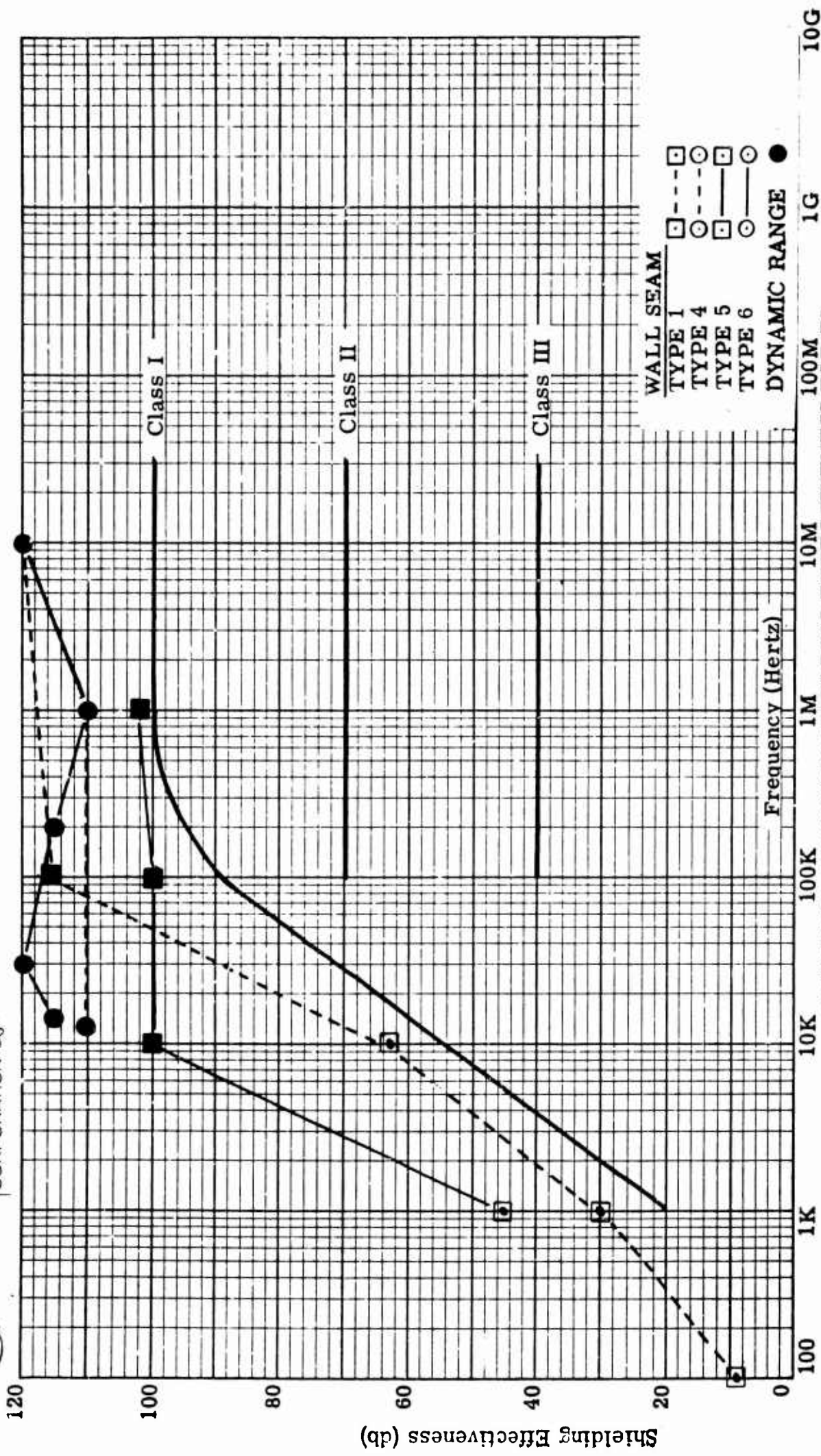


FIGURE 61 MAGNETIC SHIELDING EFFECTIVENESS FOR IN SITU SEAM TESTING OF NEW SHIELDED FACILITIES

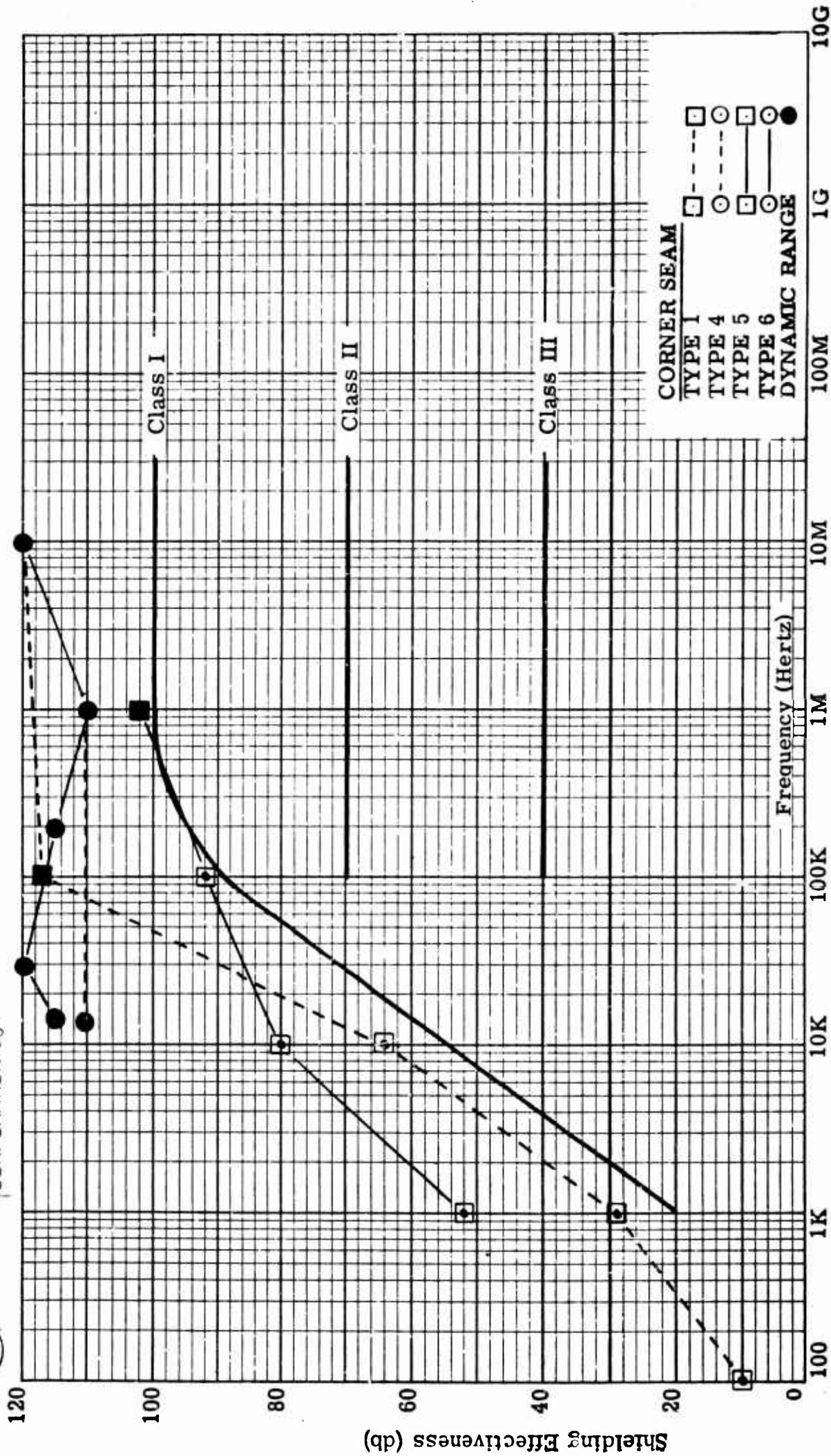


FIGURE 62 MAGNETIC SHIELDING EFFECTIVENESS FOR IN
SITU SEAM TESTING OF NEW SHIELDED FACILITIES

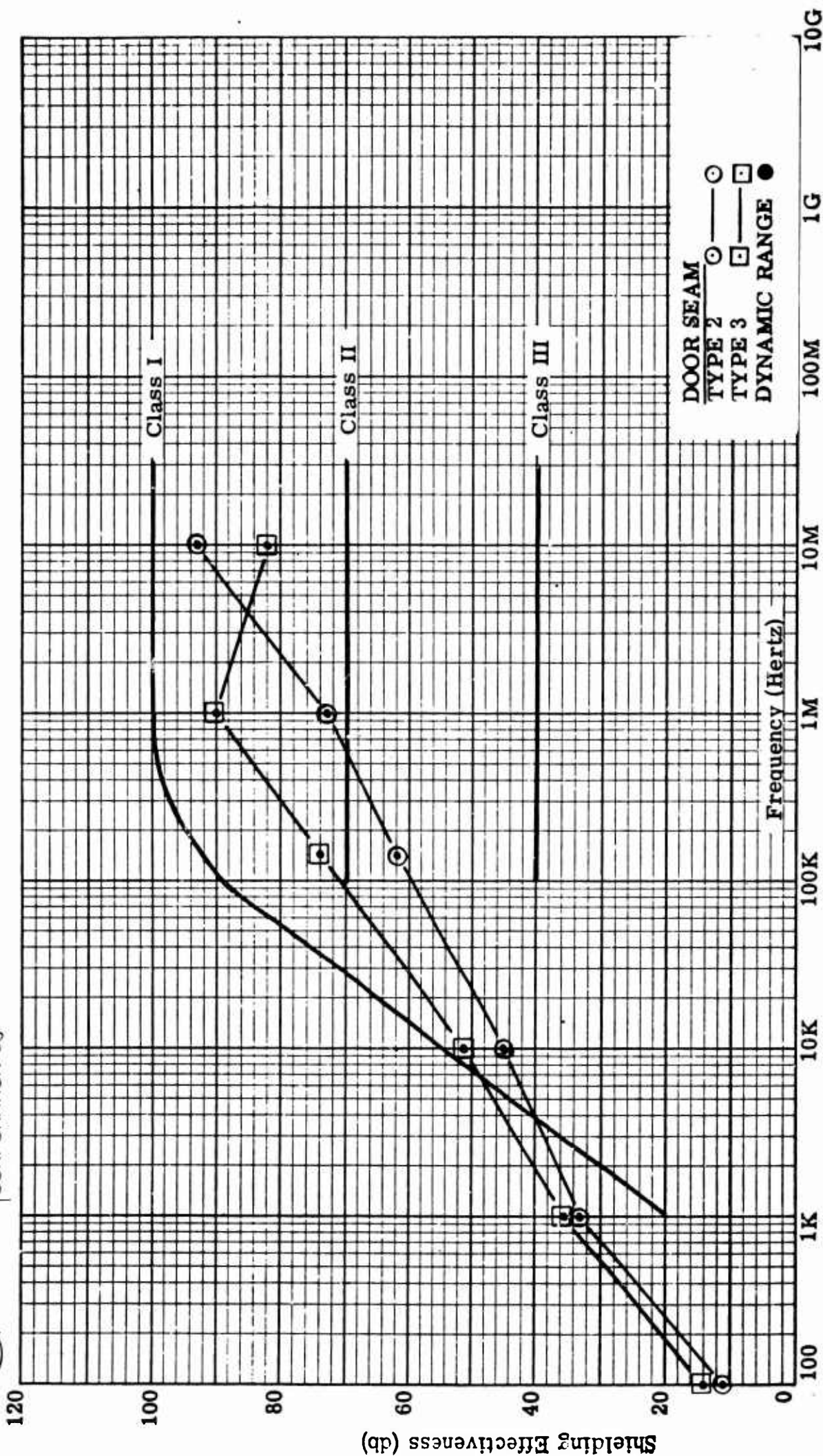


FIGURE 63 MAGNETIC SHIELDING EFFECTIVENESS FOR IN
SITU SEAM TESTING OF OLDER SHIELDED FACILITIES

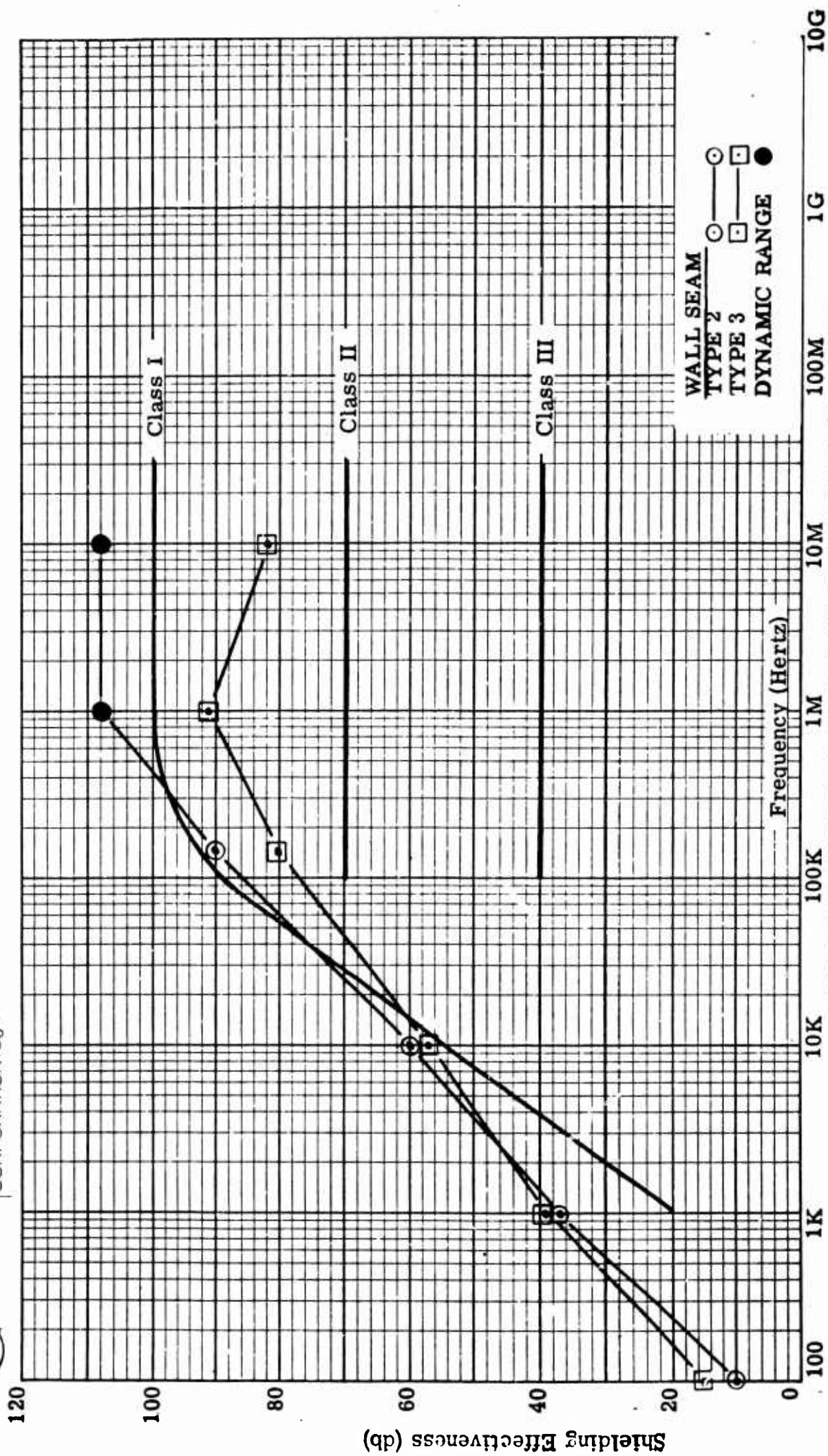


FIGURE 64 MAGNETIC SHIELDING EFFECTIVENESS FOR IN SITU SEAM TESTING OF OLDER SHIELDED FACILITIES

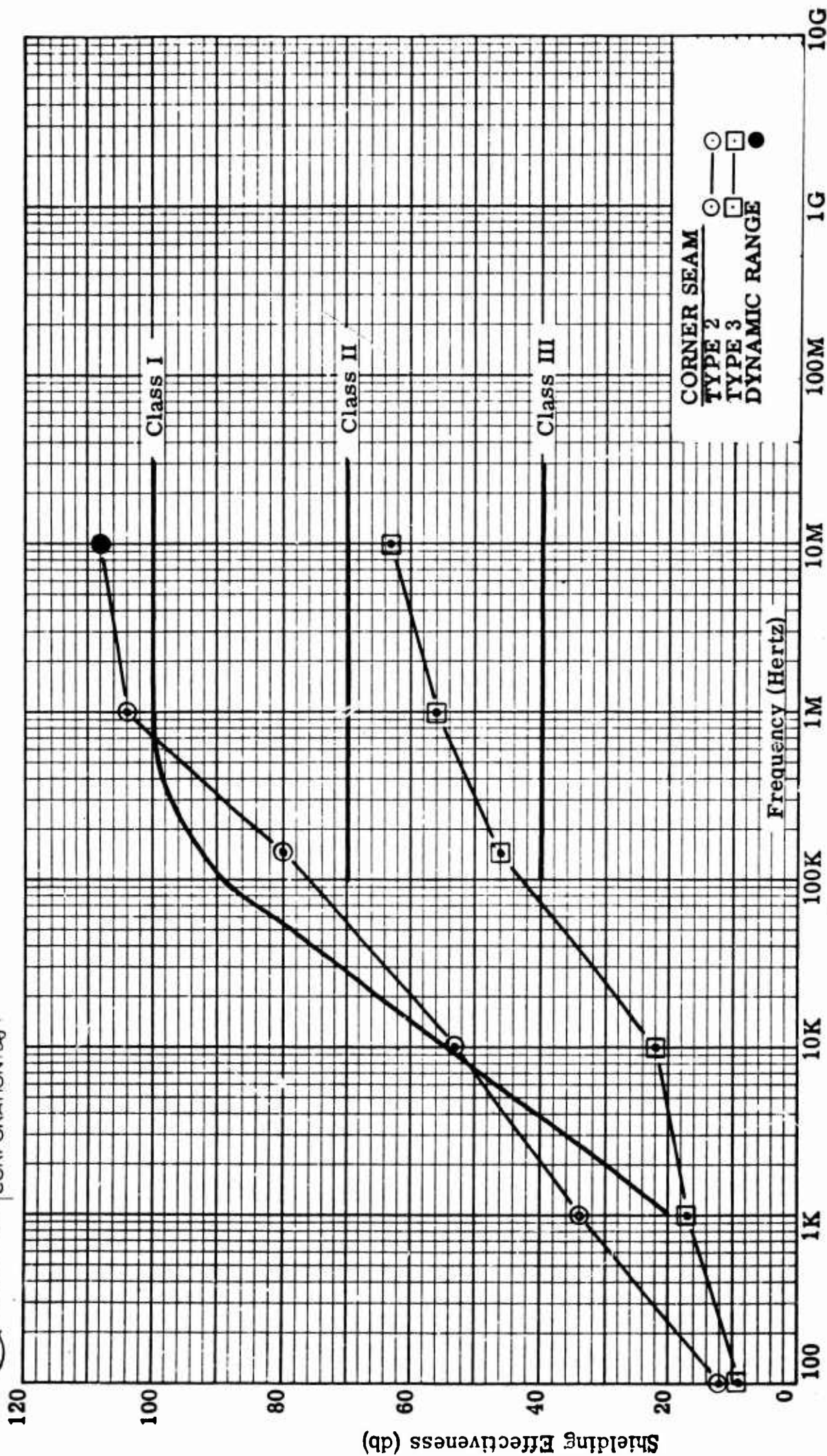


FIGURE 65 MAGNETIC SHIELDING EFFECTIVENESS FOR IN SITU SEAM TESTING OF OLDER SHIELDED FACILITIES

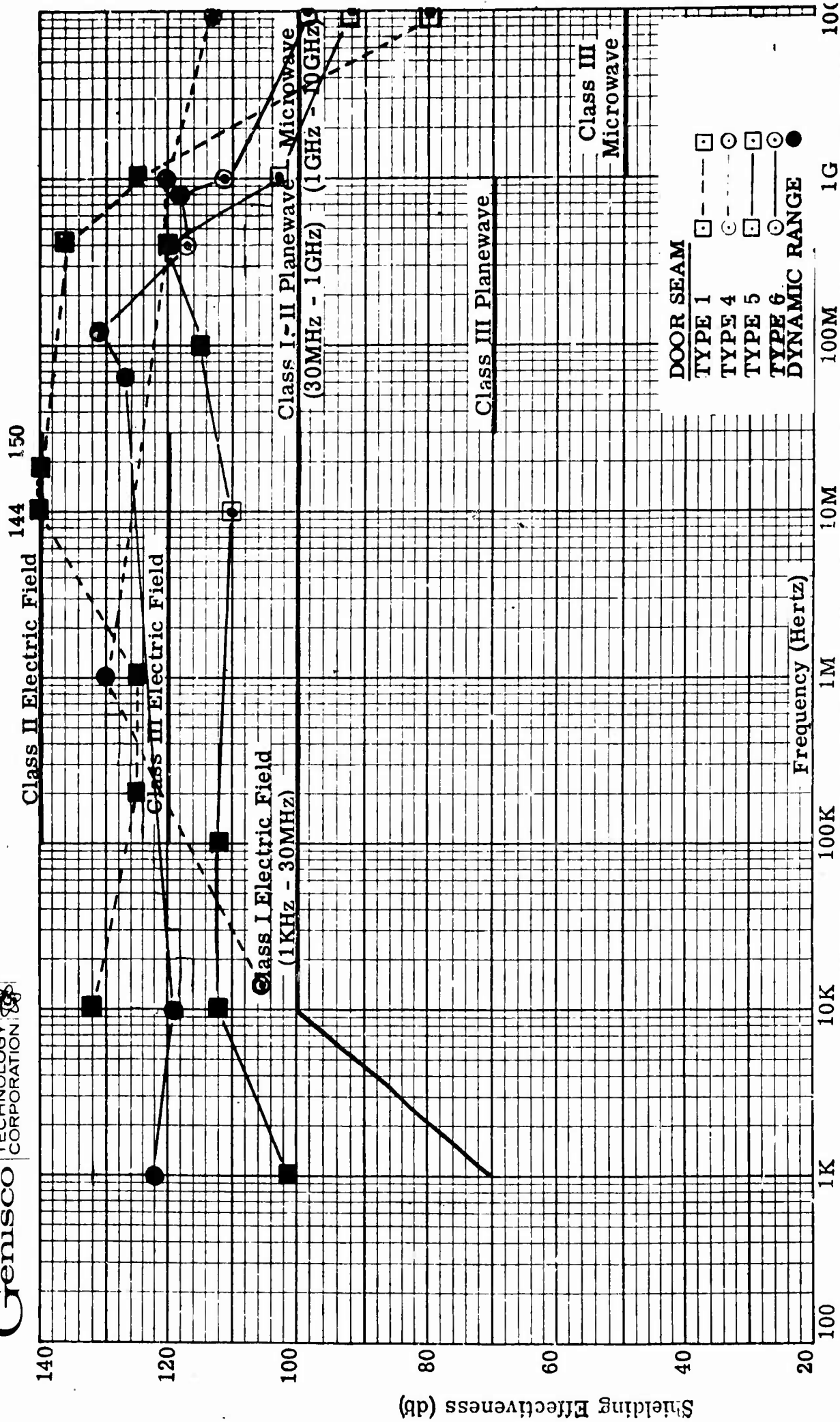


FIGURE 66 SHIELDING EFFECTIVENESS FOR ELECTRIC FIELDS, PLANEWAVES, AND MICROWAVES FOR IN SITU SEAM TESTING OF NEW SHIELDED FACILITIES

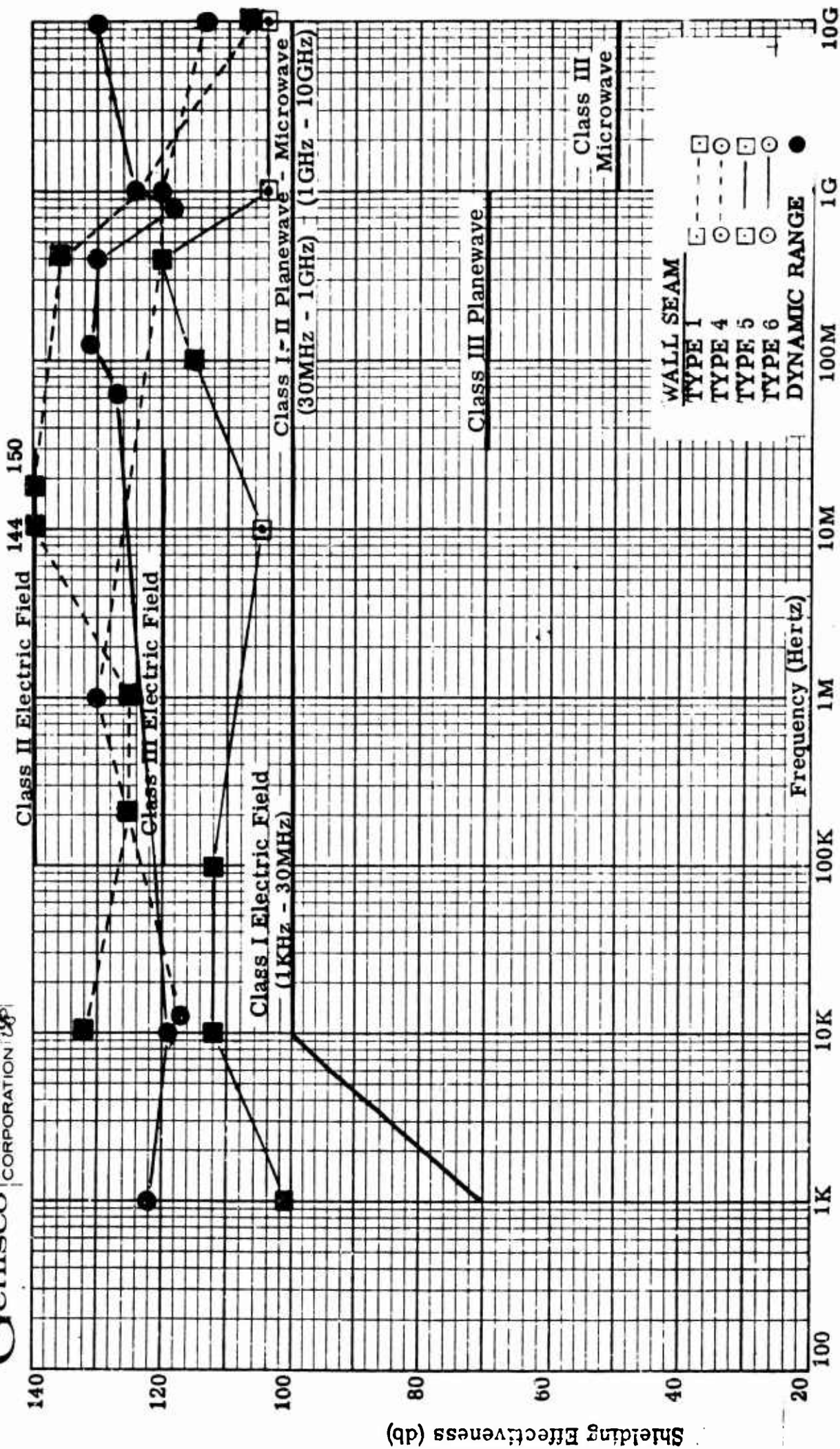


FIGURE 67 SHIELDING EFFECTIVENESS FOR ELECTRIC FIELDS, PLANEWAVES, AND MICROWAVES FOR IN SITU SEAM TESTING OF NEW SHIELDED FACILITIES

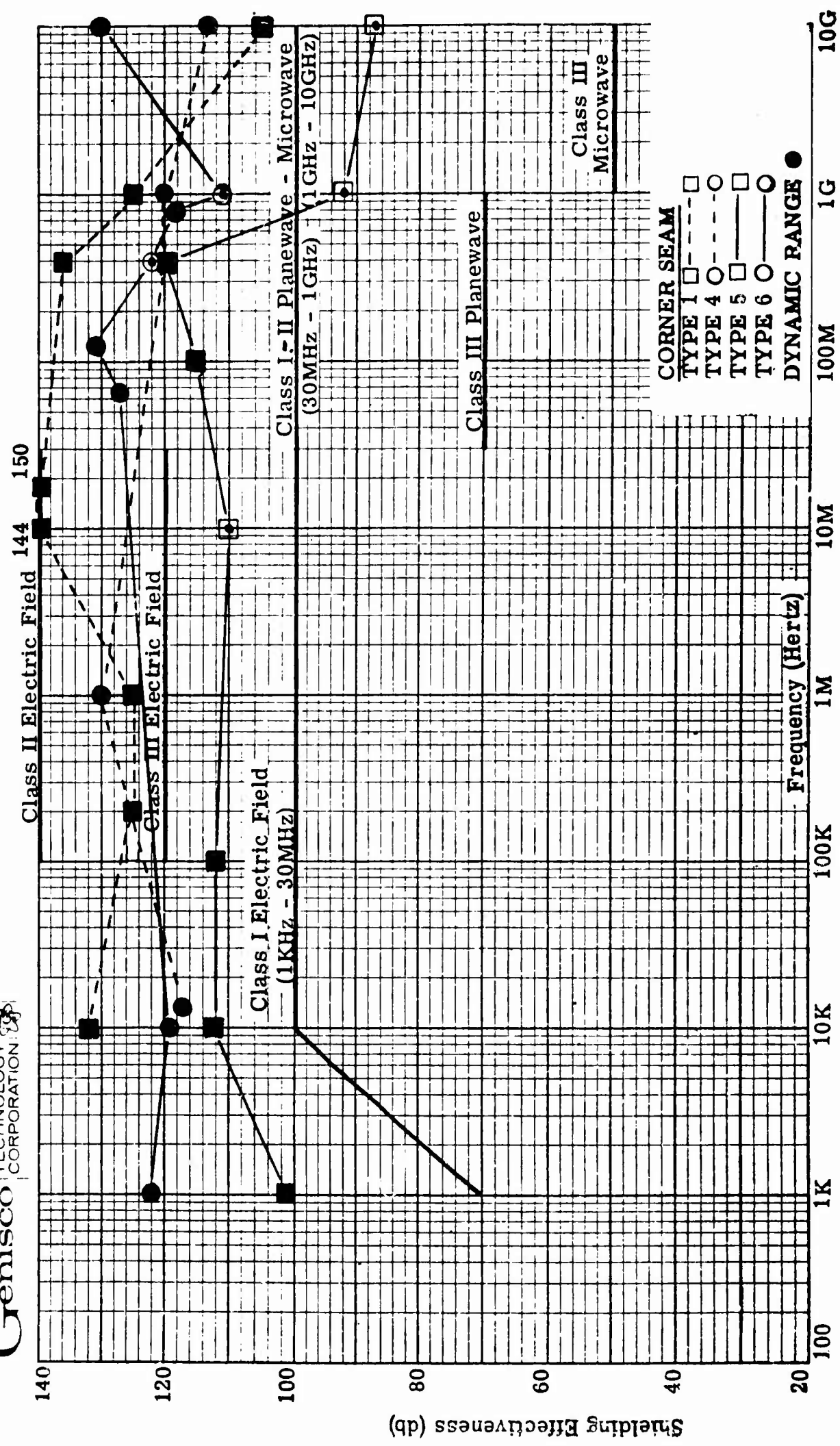


FIGURE 68 SHIELDING EFFECTIVENESS FOR ELECTRIC FIELDS, PLANEWAVES, AND MICROWAVES FOR IN SITU SEAM TESTING OF NEW SHIELDED FACILITIES

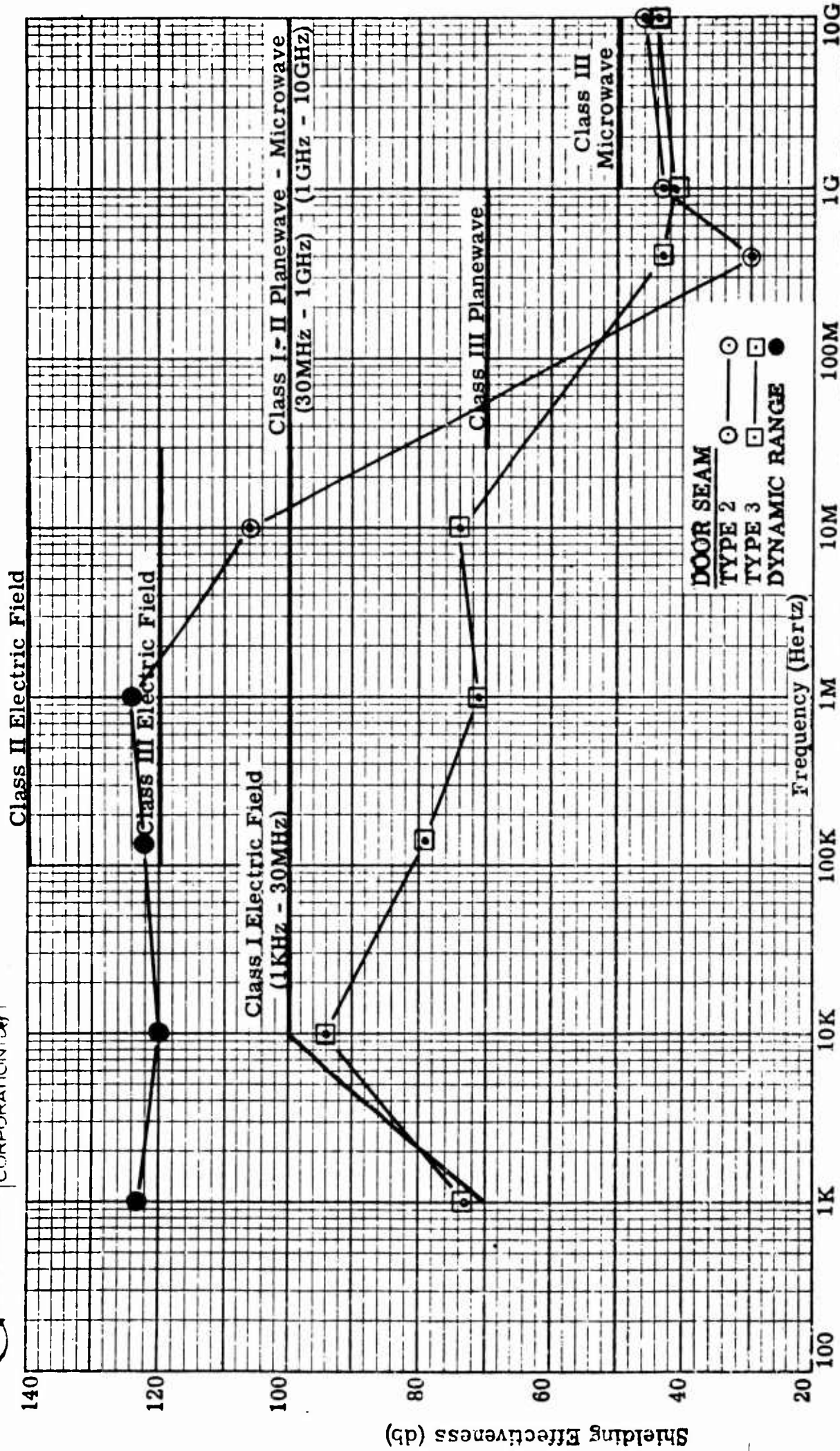


FIGURE 69 SHIELDING EFFECTIVENESS FOR ELECTRIC FIELDS, PLANEWAVES, AND MICROWAVES
FOR IN SITU SEAM TESTING OF OLDER SHIELDED FACILITIES

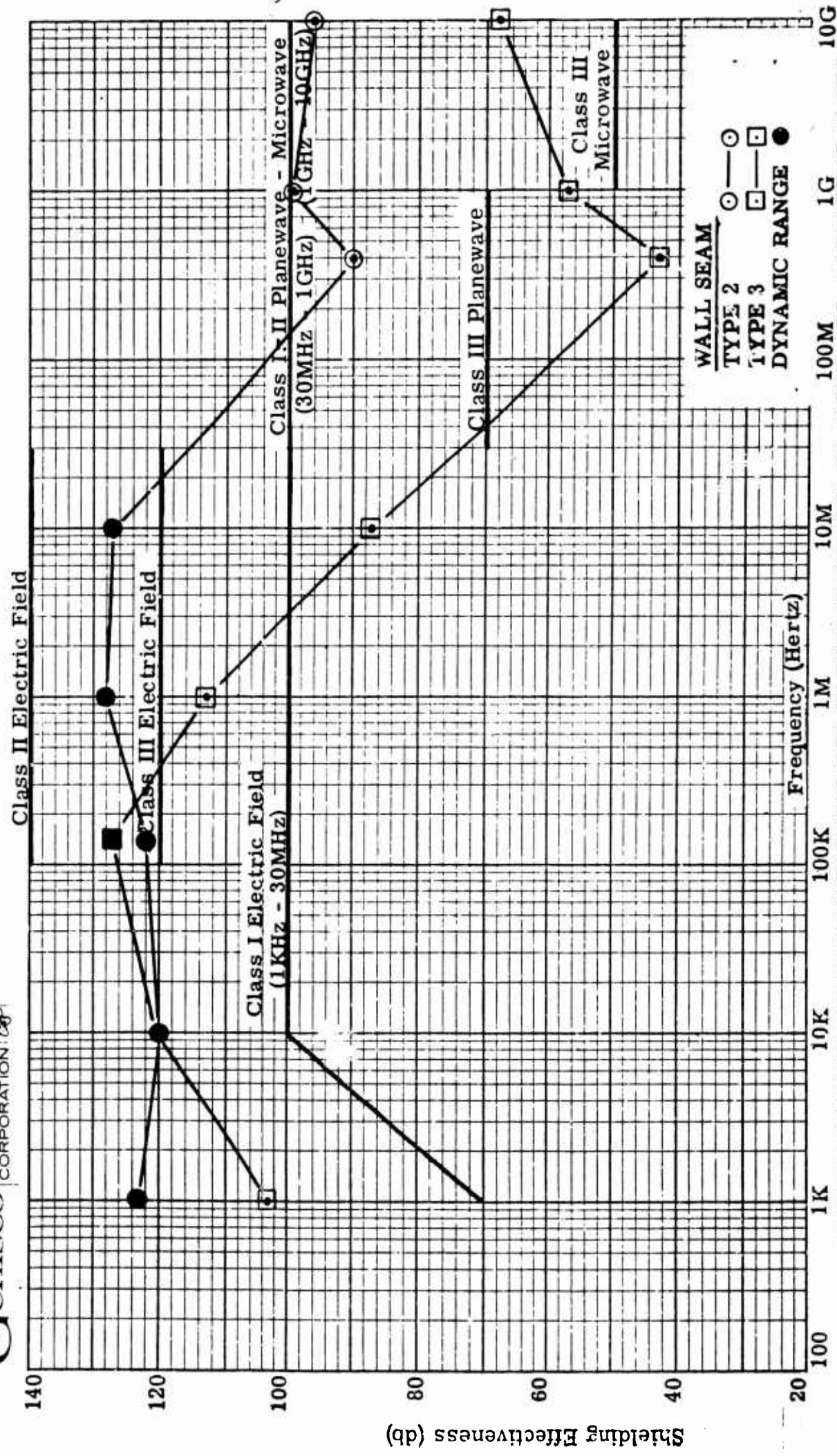


FIGURE 70 SHIELDING EFFECTIVENESS FOR ELECTRIC FIELDS, PLANEWAVES, AND MICROWAVES FOR IN SITU SEAM TESTING OF OLDER SHIELDED FACILITIES

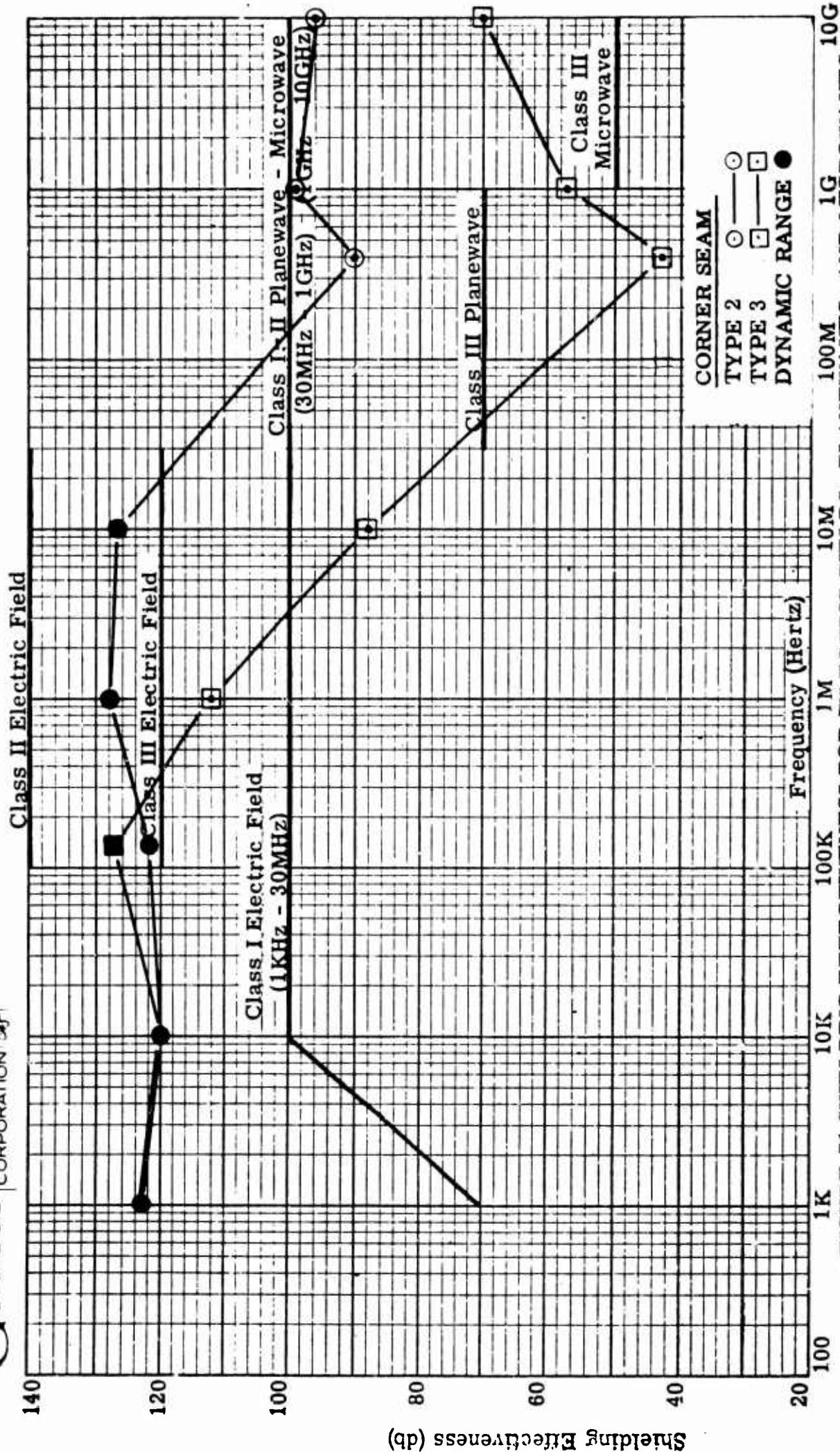


FIGURE 71 SHIELDING EFFECTIVENESS FOR ELECTRIC FIELDS, PLANEWAVES, AND MICROWAVES
FOR IN SITU SEAM TESTING OF OLDER SHIELDED FACILITIES

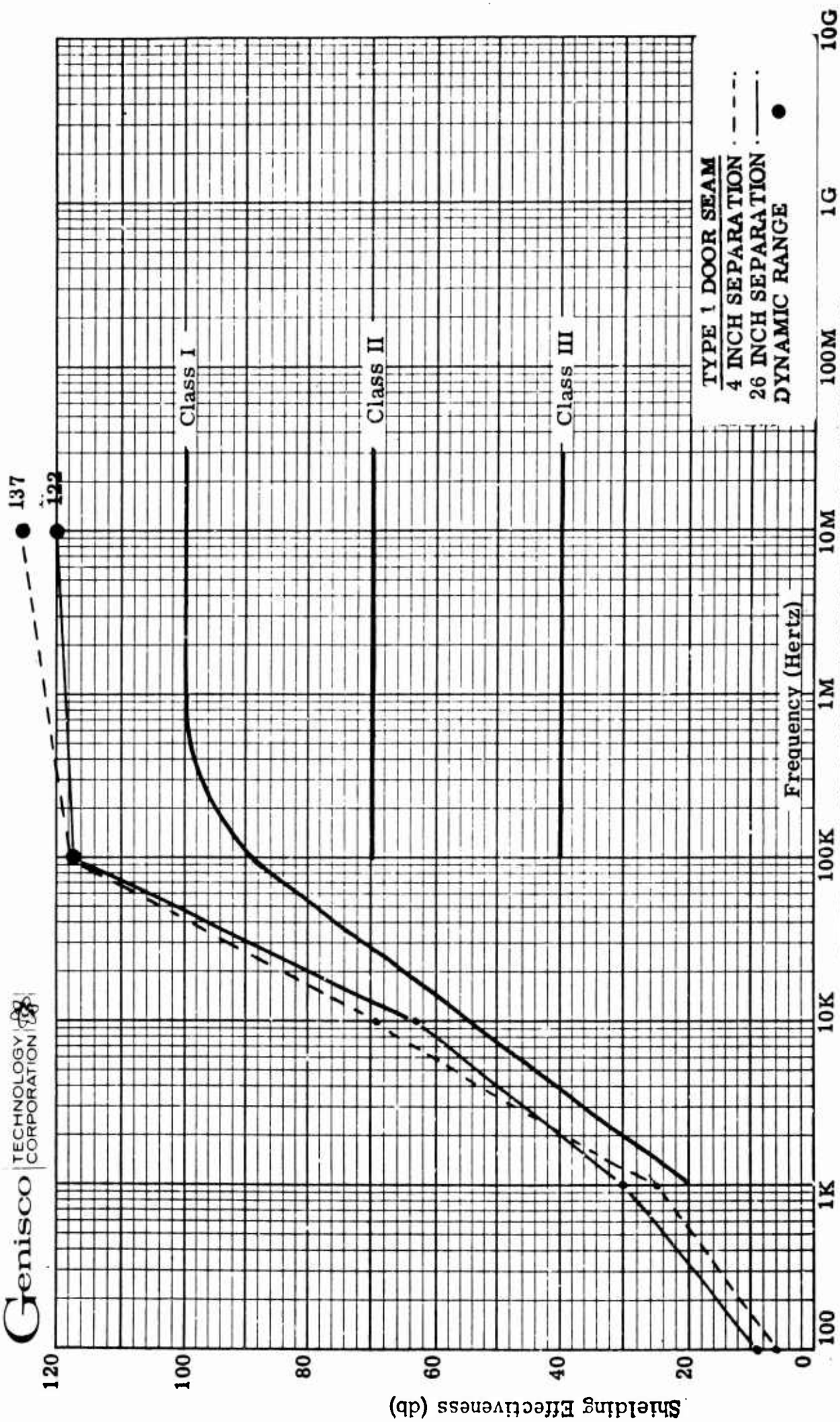


FIGURE 72 MAGNETIC SHIELDING EFFECTIVENESS FOR IN SITU SEAM TESTING WITH ANTENNA SEPARATION 4 AND 26 INCHES

137

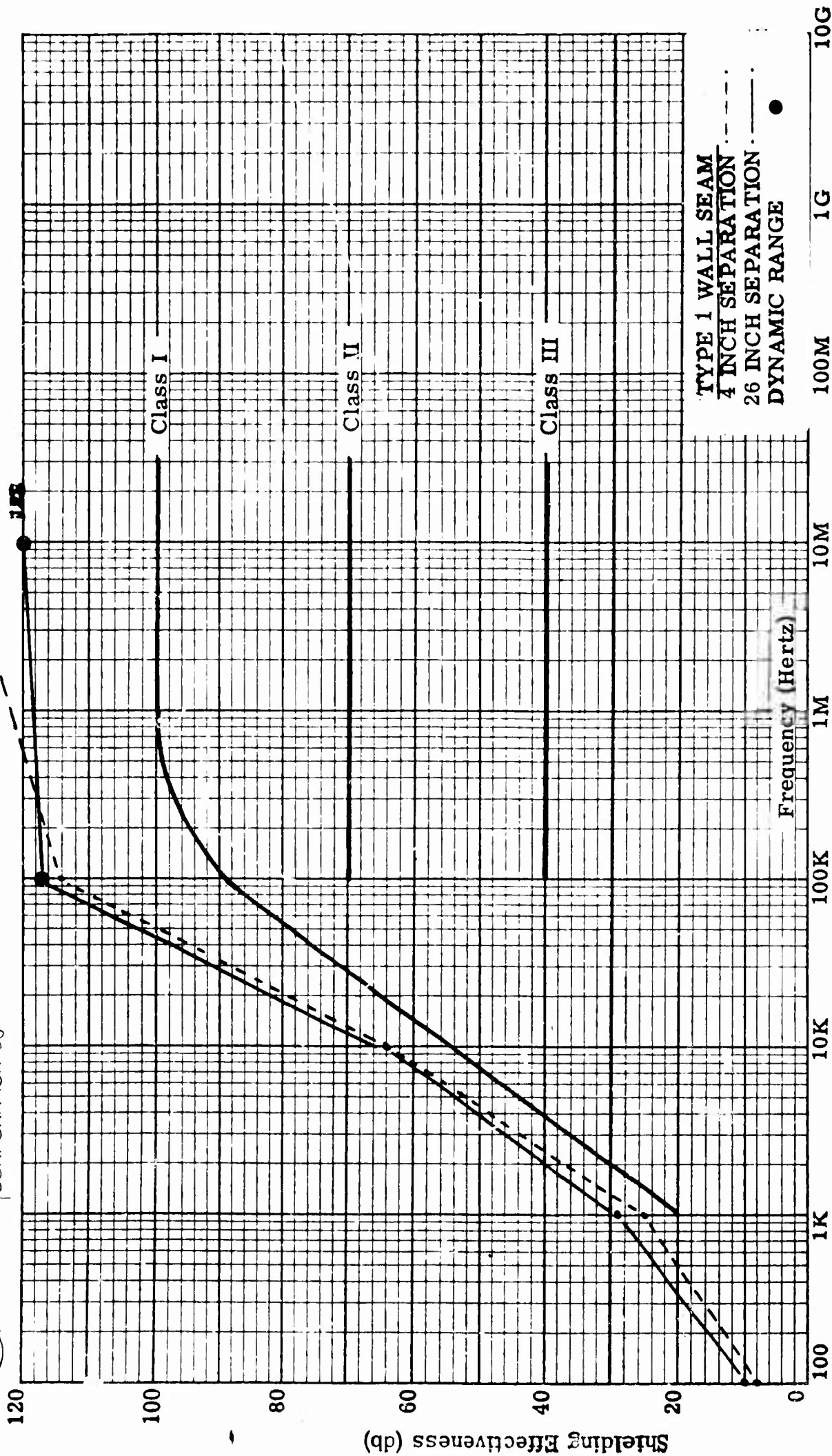


FIGURE 73 MAGNETIC SHIELDING EFFECTIVENESS FOR IN SITU SEAM TESTING WITH ANTENNA SEPARATION 4 AND 26 INCHES

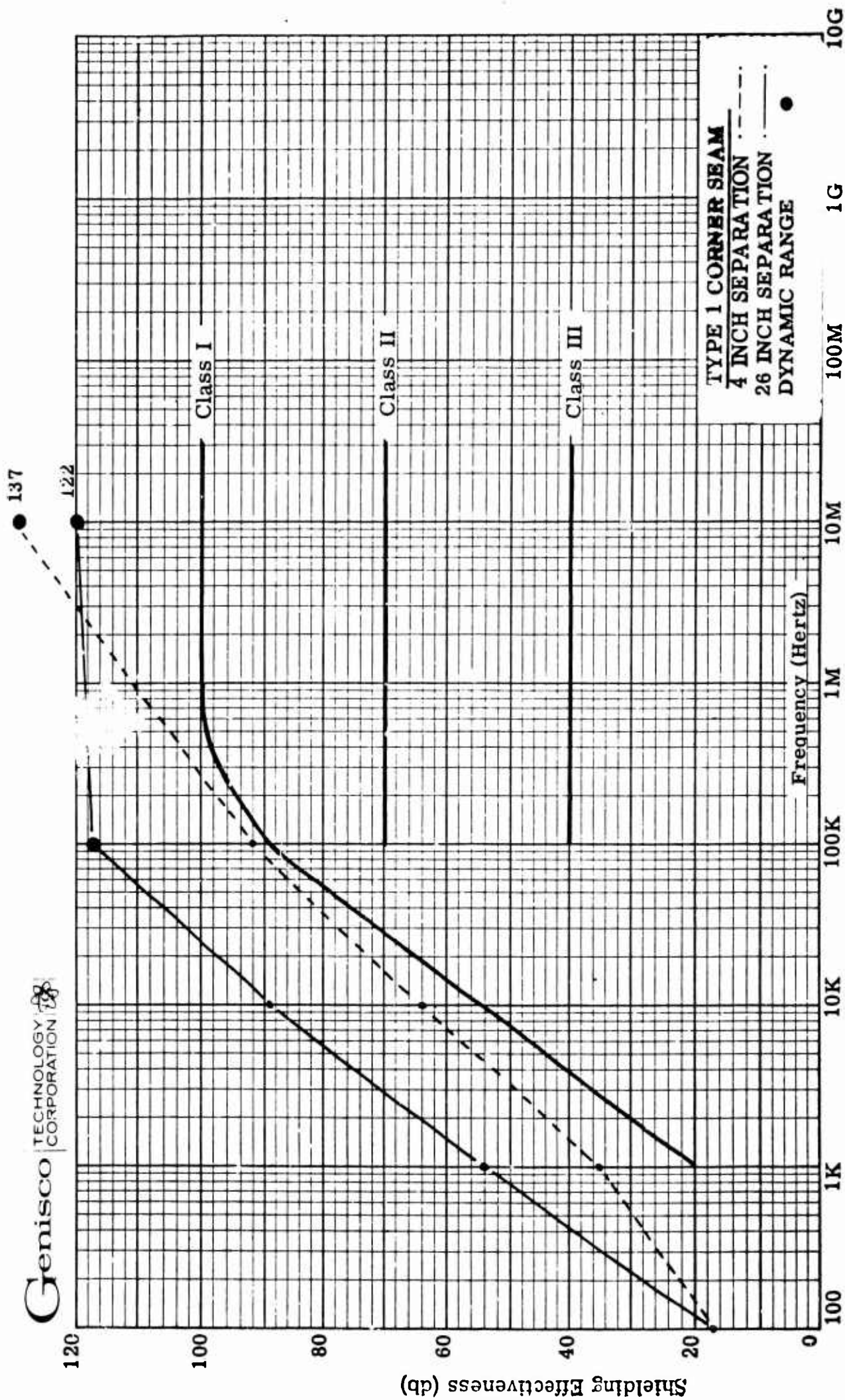


FIGURE 74 MAGNETIC SHIELDING EFFECTIVENESS FOR IN SITU SEAM TESTING WITH ANTENNA SEPARATION 4 AND 26 INCHES

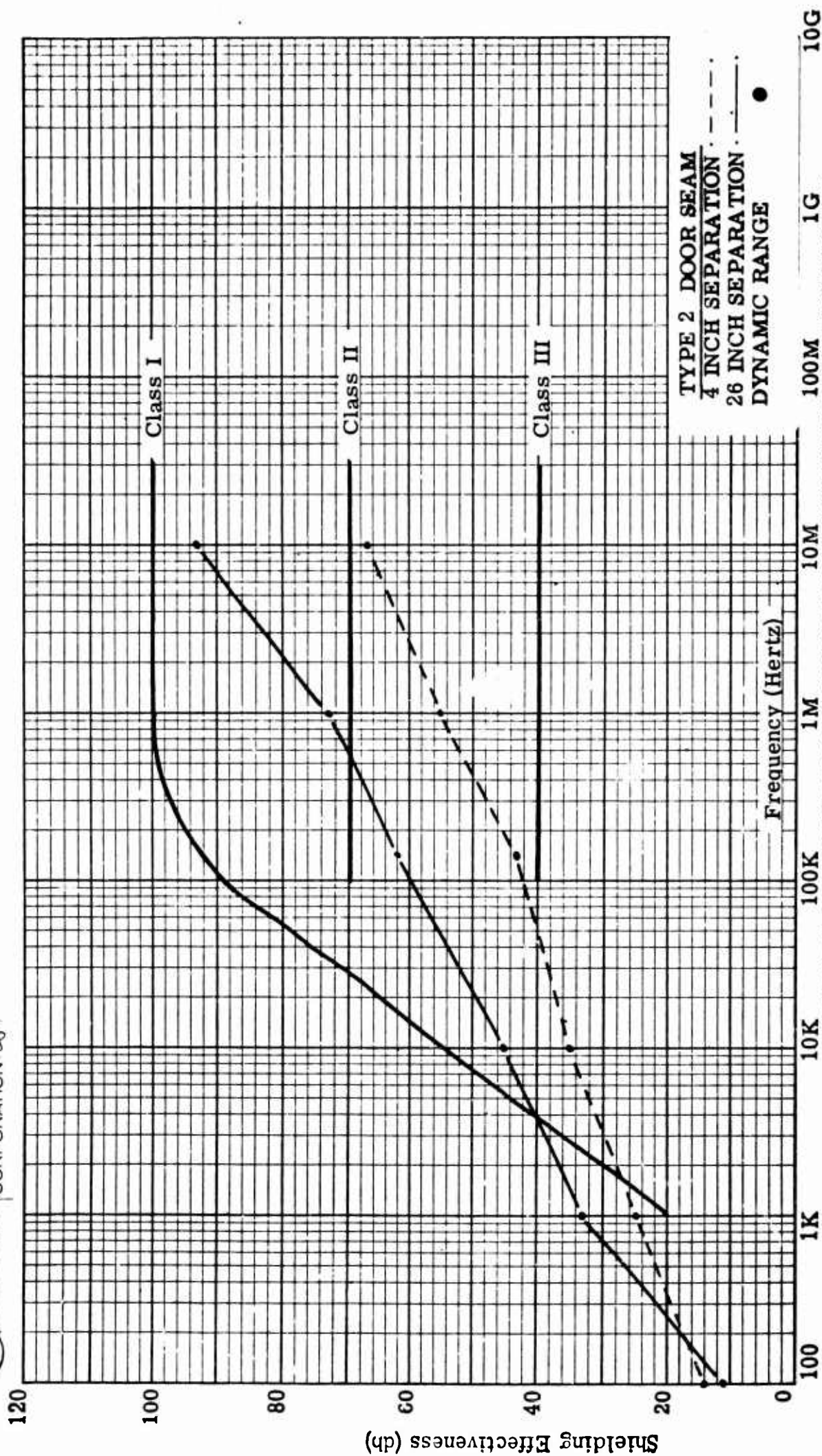


FIGURE 75 MAGNETIC SHIELDING EFFECTIVENESS FOR IN SITU SEAM
TESTIN: WITH ANTENNA SEPARATION 4 AND 26 INCHES

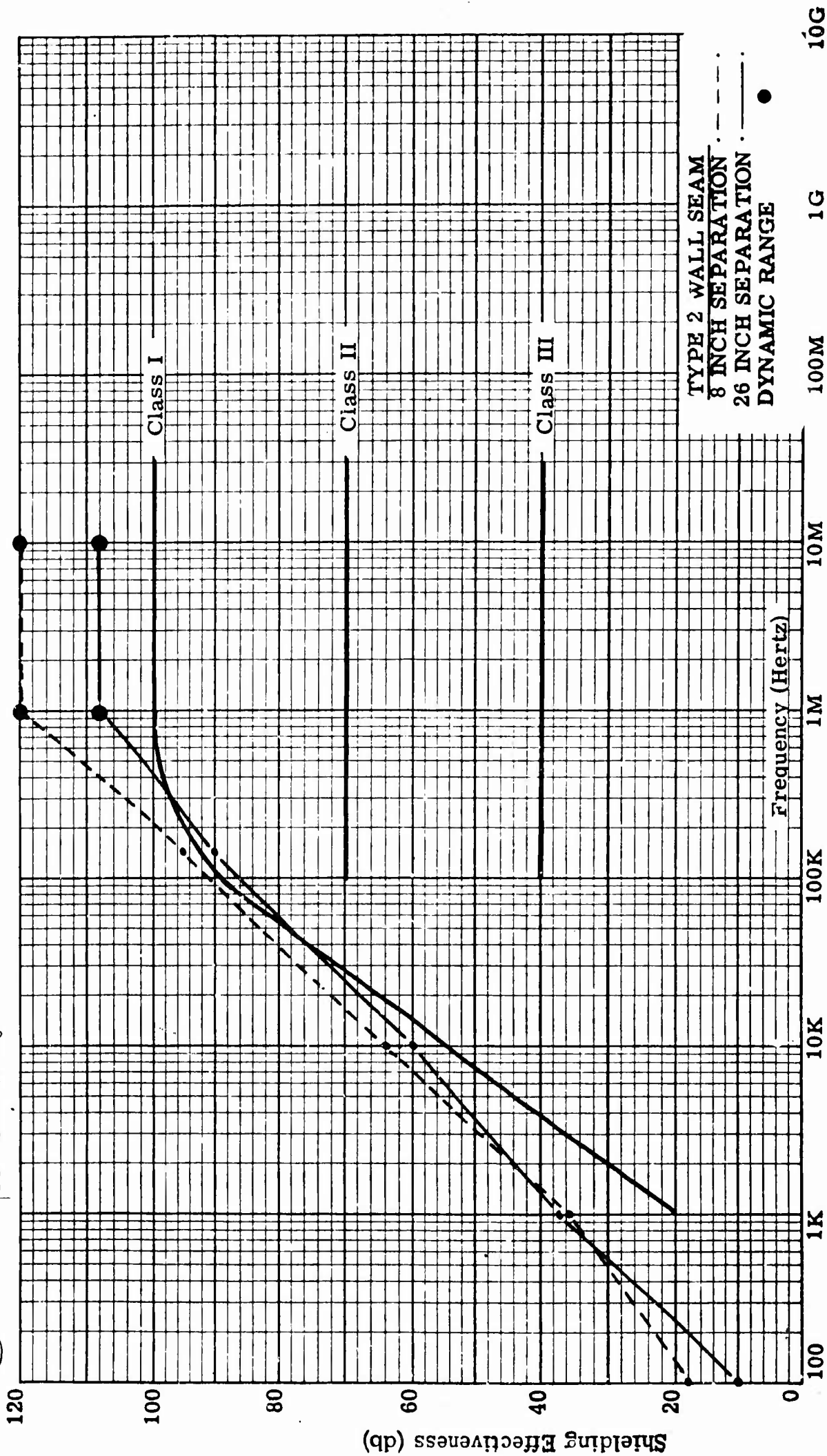


FIGURE 76 MAGNETIC SHIELDING EFFECTIVENESS FOR IN SITU SEAM TESTING WITH ANTENNA SEPARATION 8 AND 26 INCHES

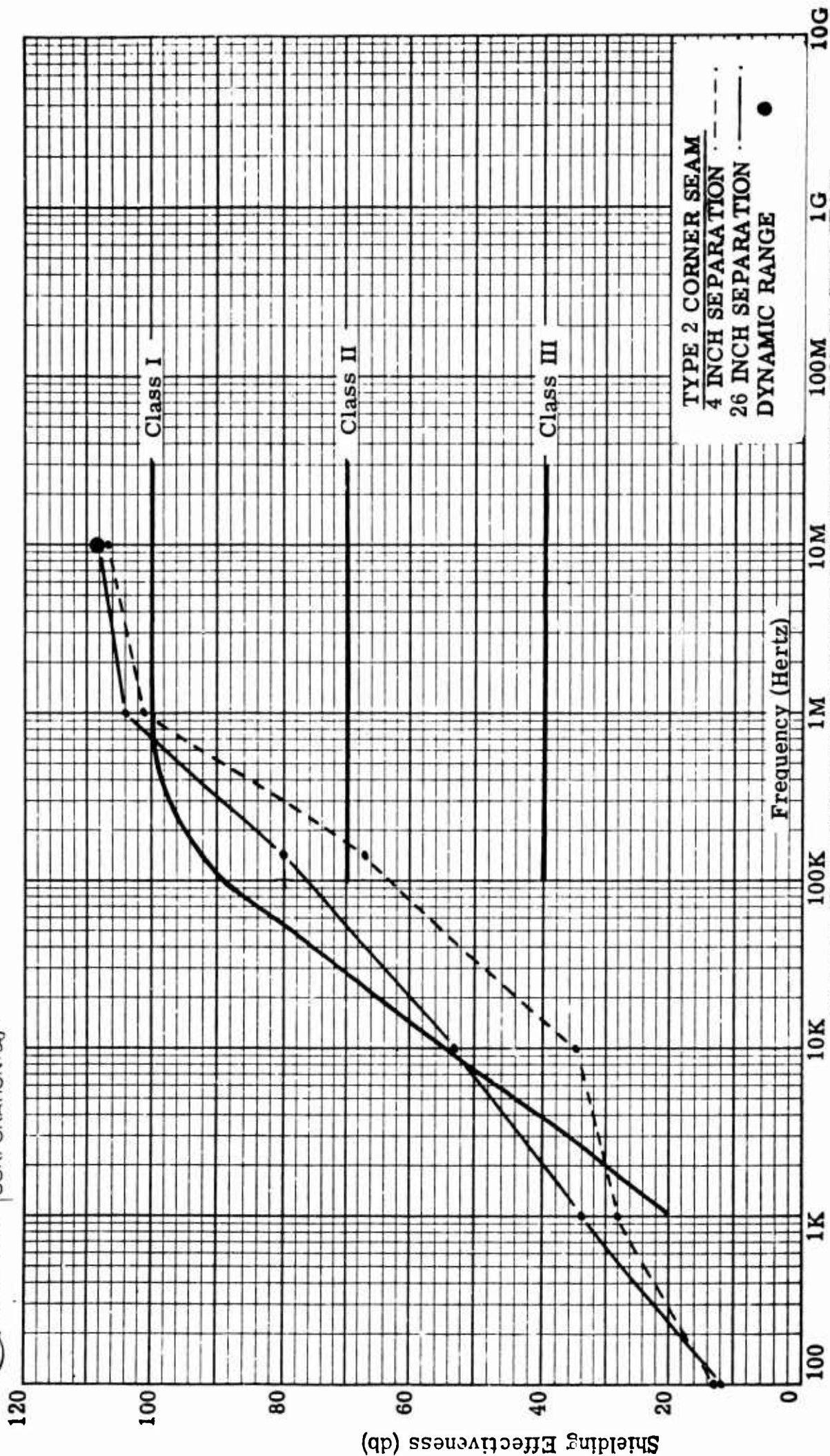
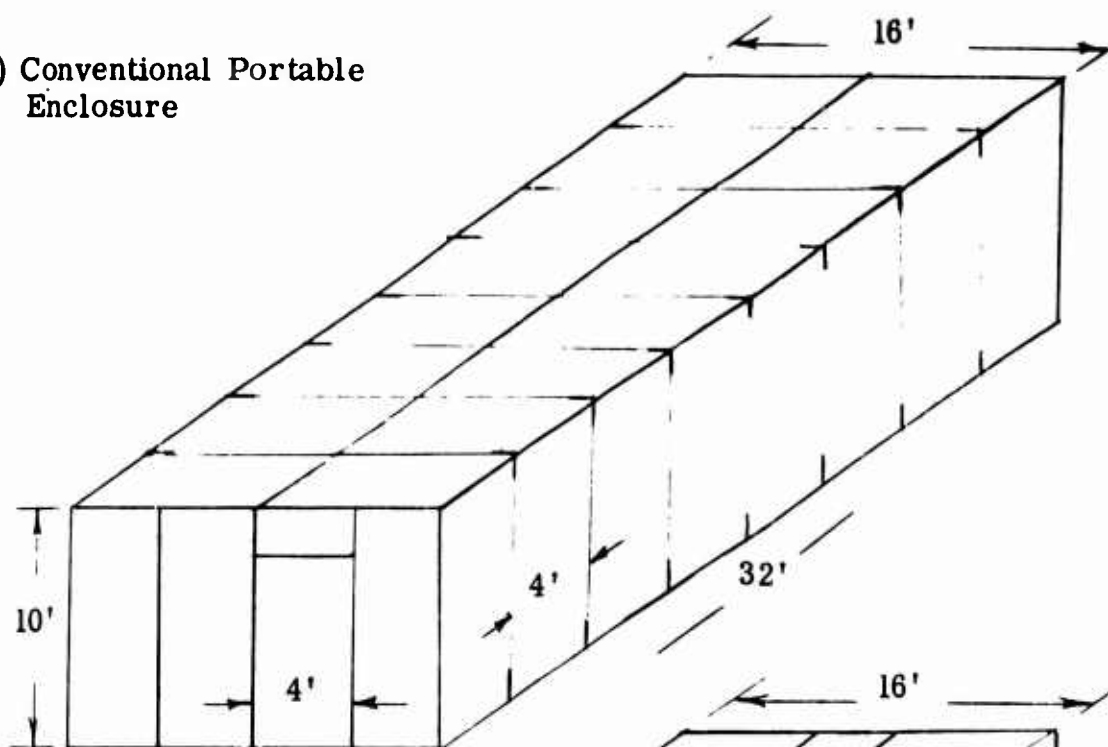
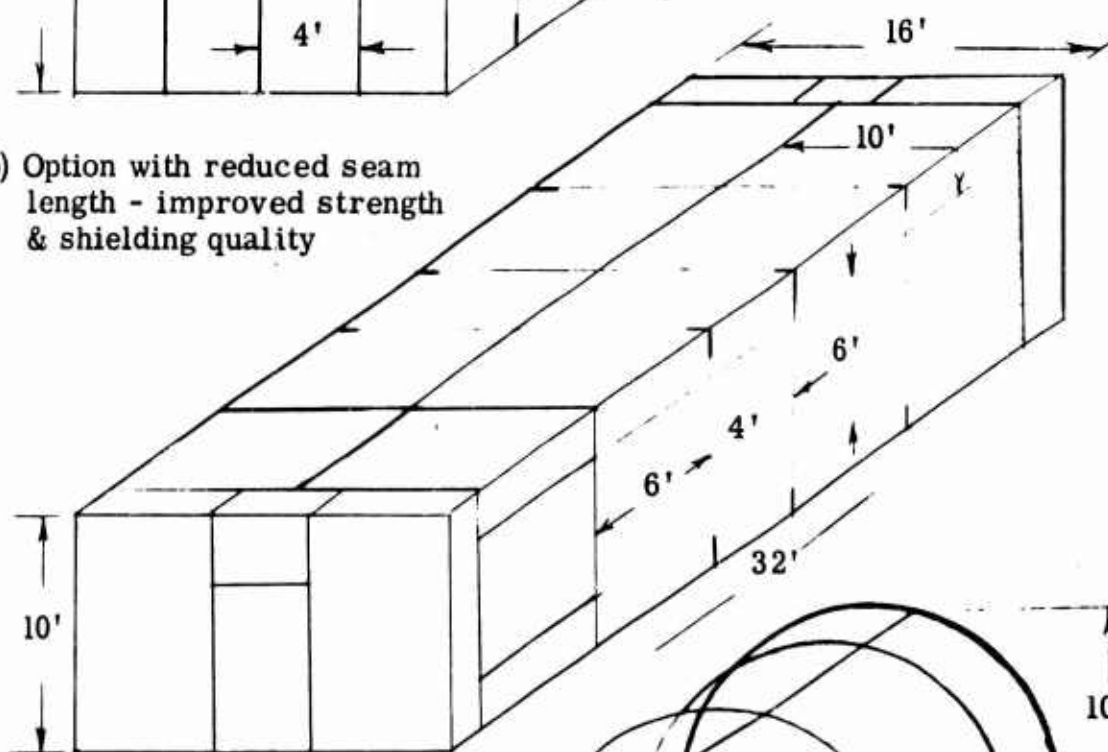


FIGURE 77 MAGNETIC SHIELDING EFFECTIVENESS FOR IN SITU SEAM TESTING WITH ANTENNA SEPARATION 4 AND 26 INCHES

(a) Conventional Portable Enclosure



(b) Option with reduced seam length - improved strength & shielding quality



(c) Option with minimum seam length - maximum strength & shielding quality

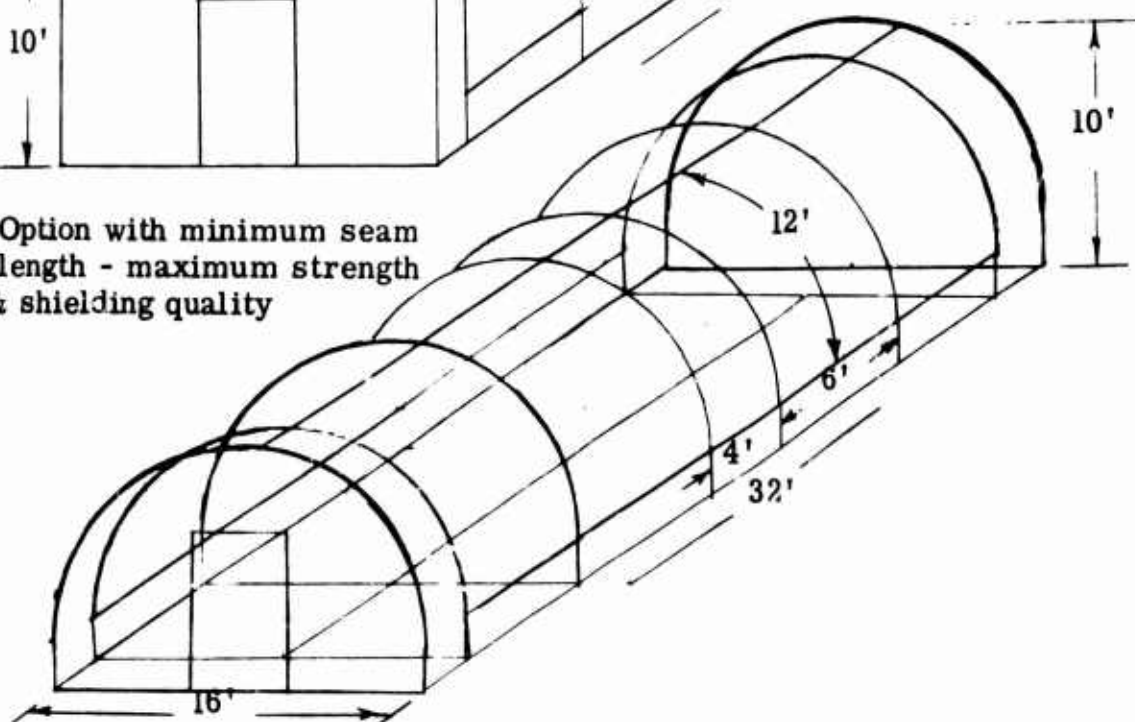
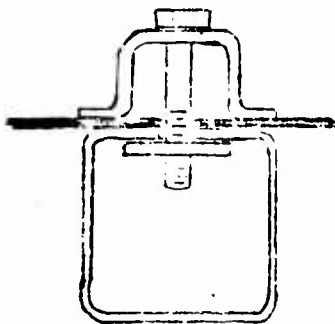
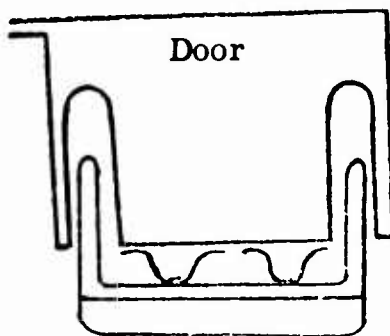
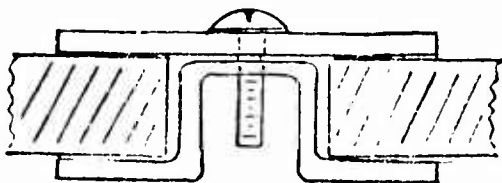
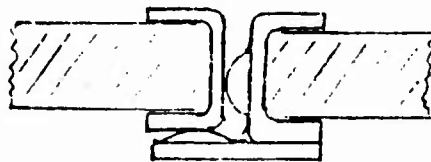


Figure 78- Preliminary Portable Shelter Design Concepts

**FIGURE 79
DOOR AND WALL SEAM TYPES**



Type 8



Type 9

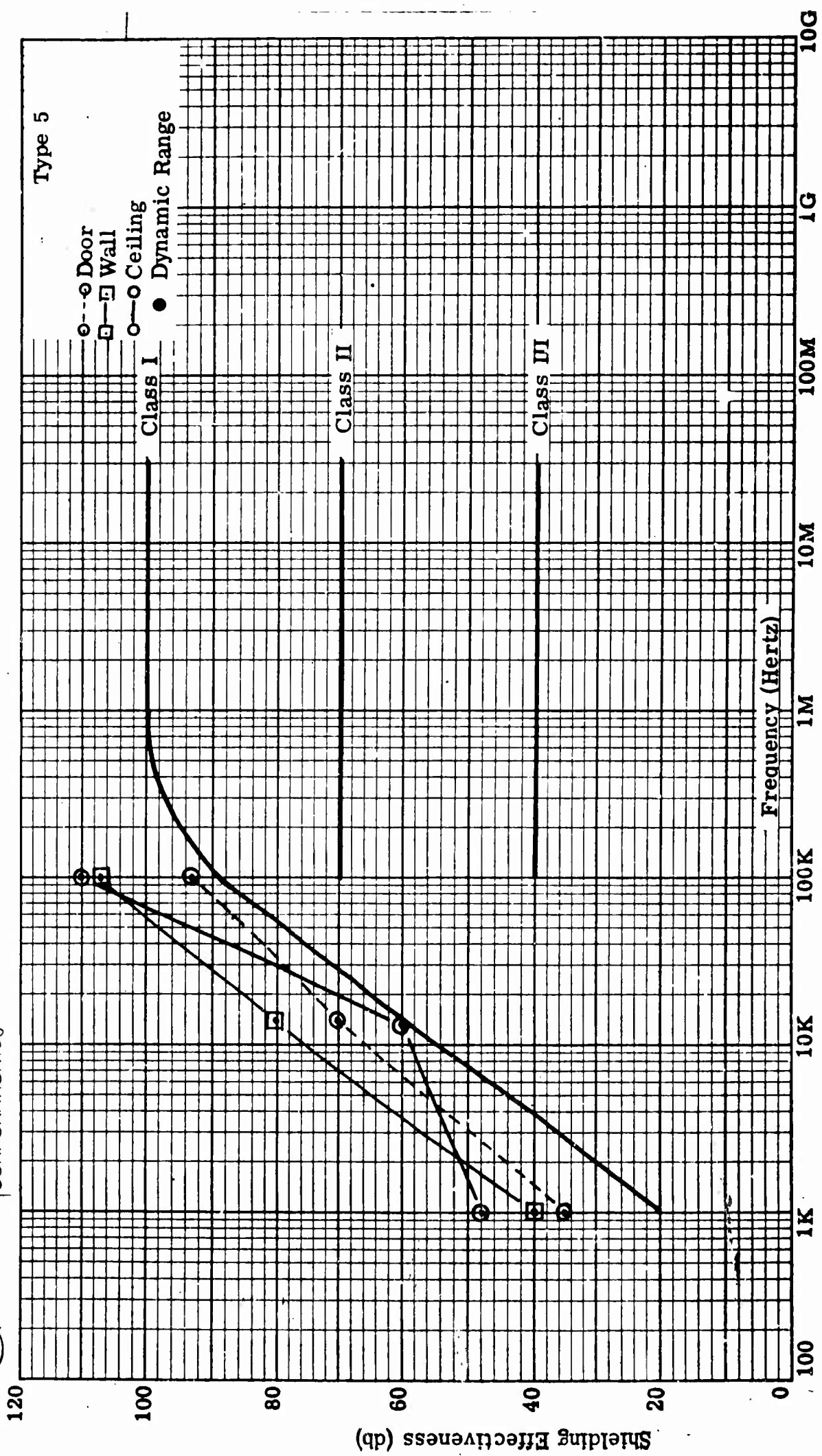


FIGURE 80
 MAGNETIC SHIELDING EFFECTIVENESS
 FOR IN SITU SEAM TESTING OF NEW SHIELDED FACILITIES

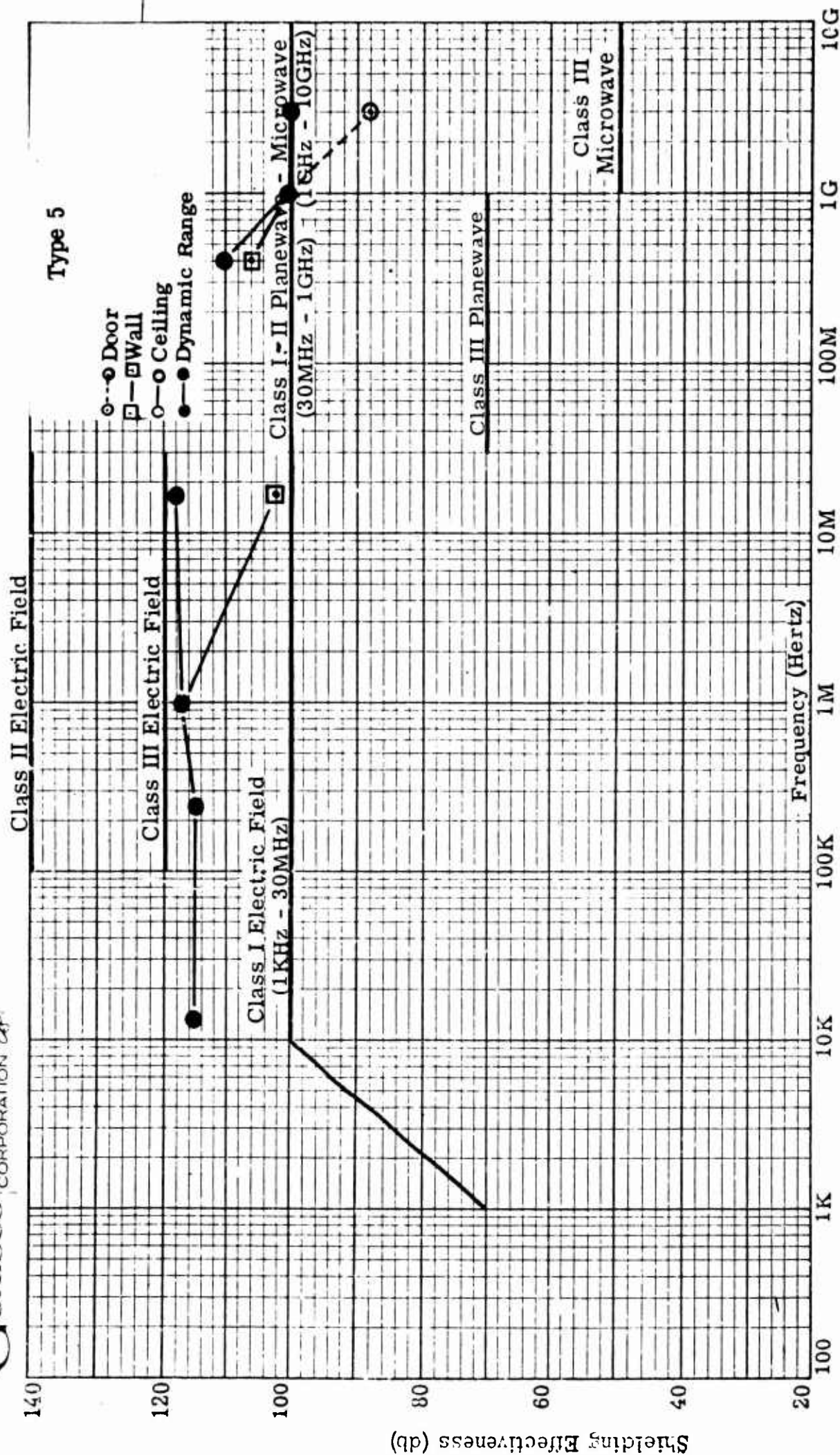


FIGURE 81
 SHIELDING EFFECTIVENESS FOR ELECTRIC FIELDS, PLANEWAVES, AND MICROWAVES
 FOR IN SITU SEAM TESTING OF NEW SHIELDED FACILITIES

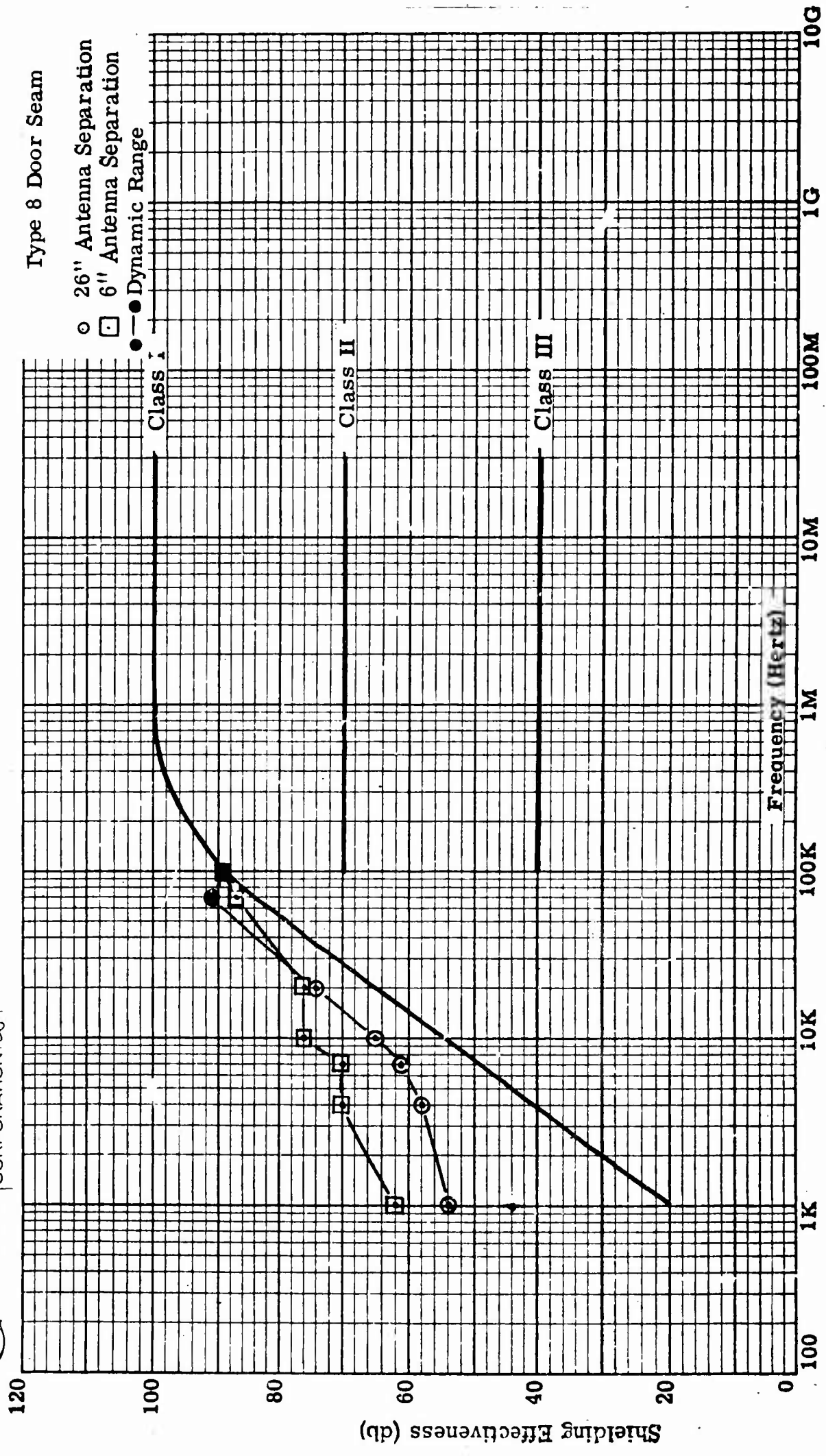


FIGURE 82
 MAGNETIC SHIELDING EFFECTIVENESS
 FOR IN SITU SEAM TESTING OF NEW SHIELDED FACILITIES

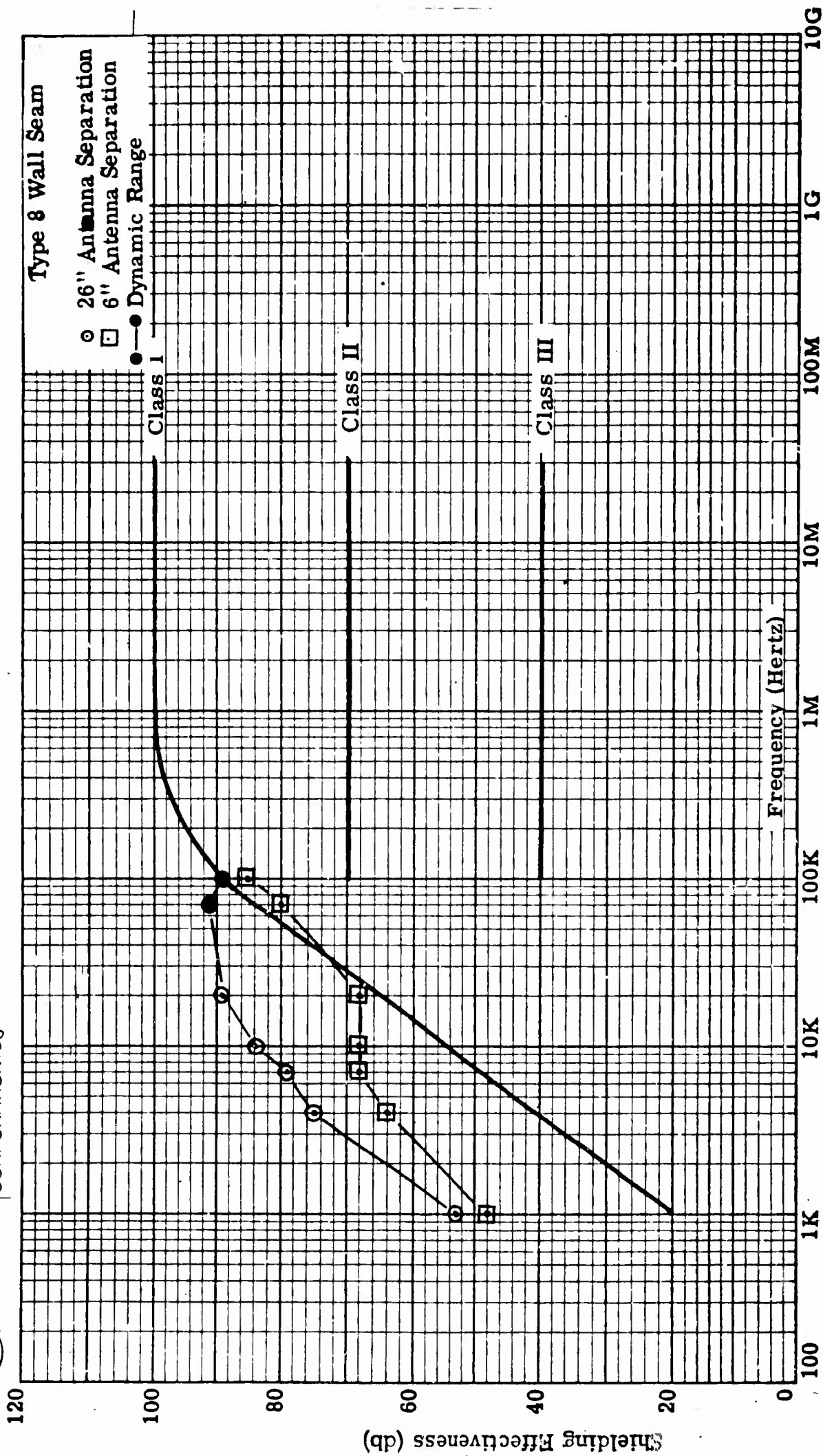


FIGURE 83
 MAGNETIC SHIELDING EFFECTIVENESS
 FOR IN SITU SEAM TESTING OF NEW SHIELDED FACILITIES

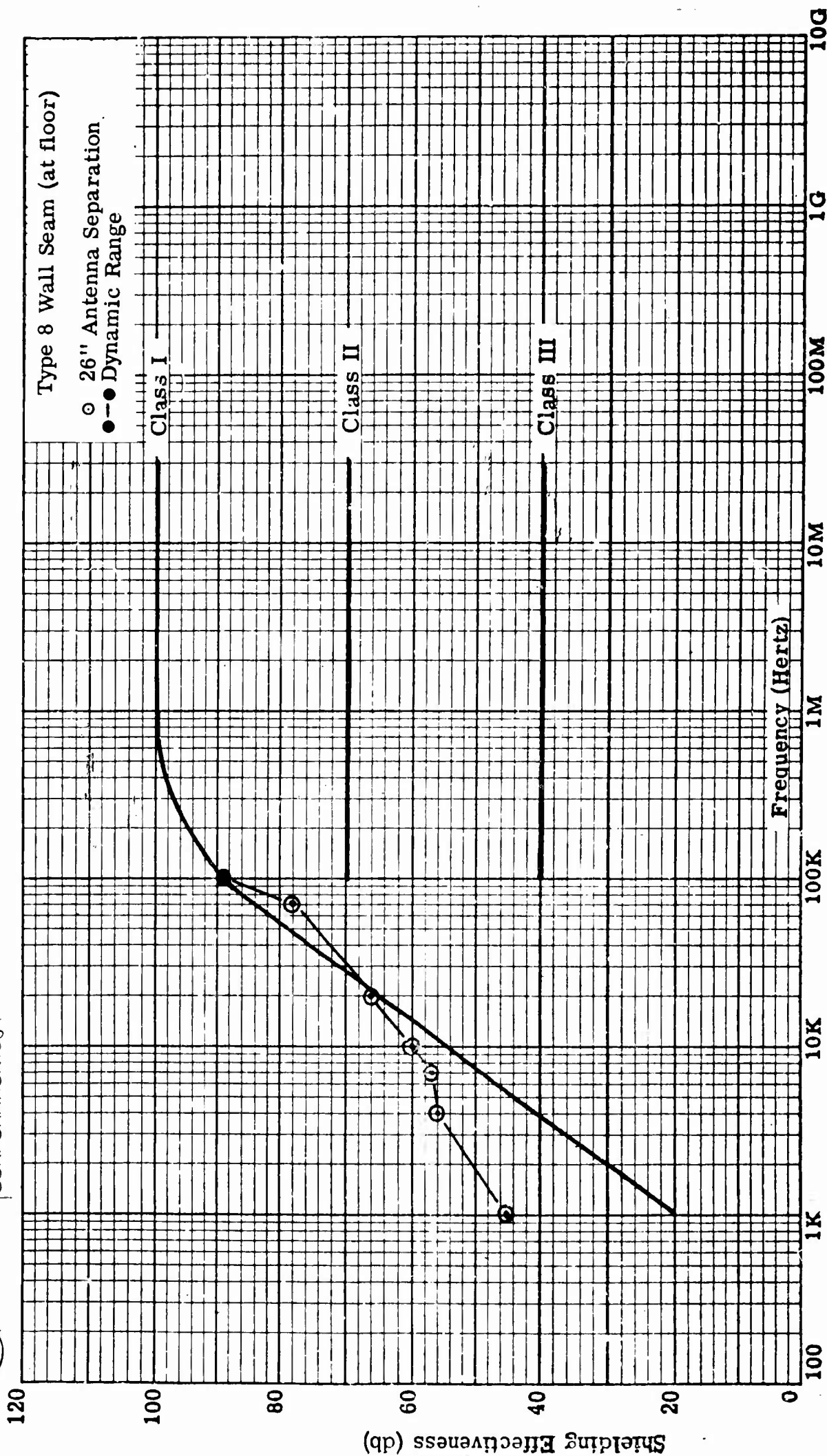
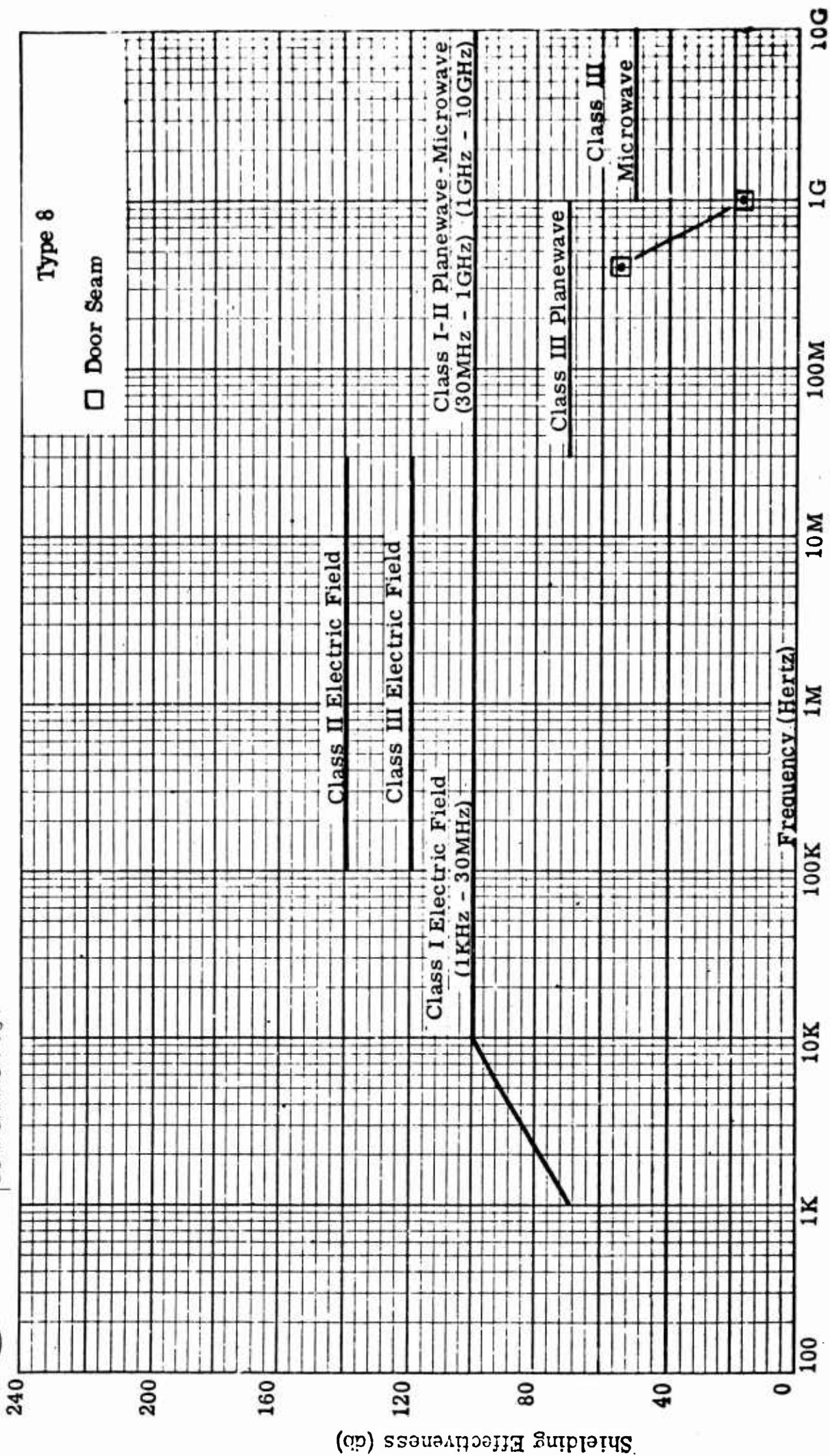


FIGURE 84
MAGNETIC SHIELDING EFFECTIVENESS
FOR IN SITU SEAM TESTING OF NEW SHIELDED FACILITIES



SHIELDING EFFECTIVENESS FOR ELECTRIC FIELDS, PLANEWAVES, AND MICROWAVES
FOR IN SITU SEAM TESTING OF NEW SHIELDED FACILITIES

FIGURE 85

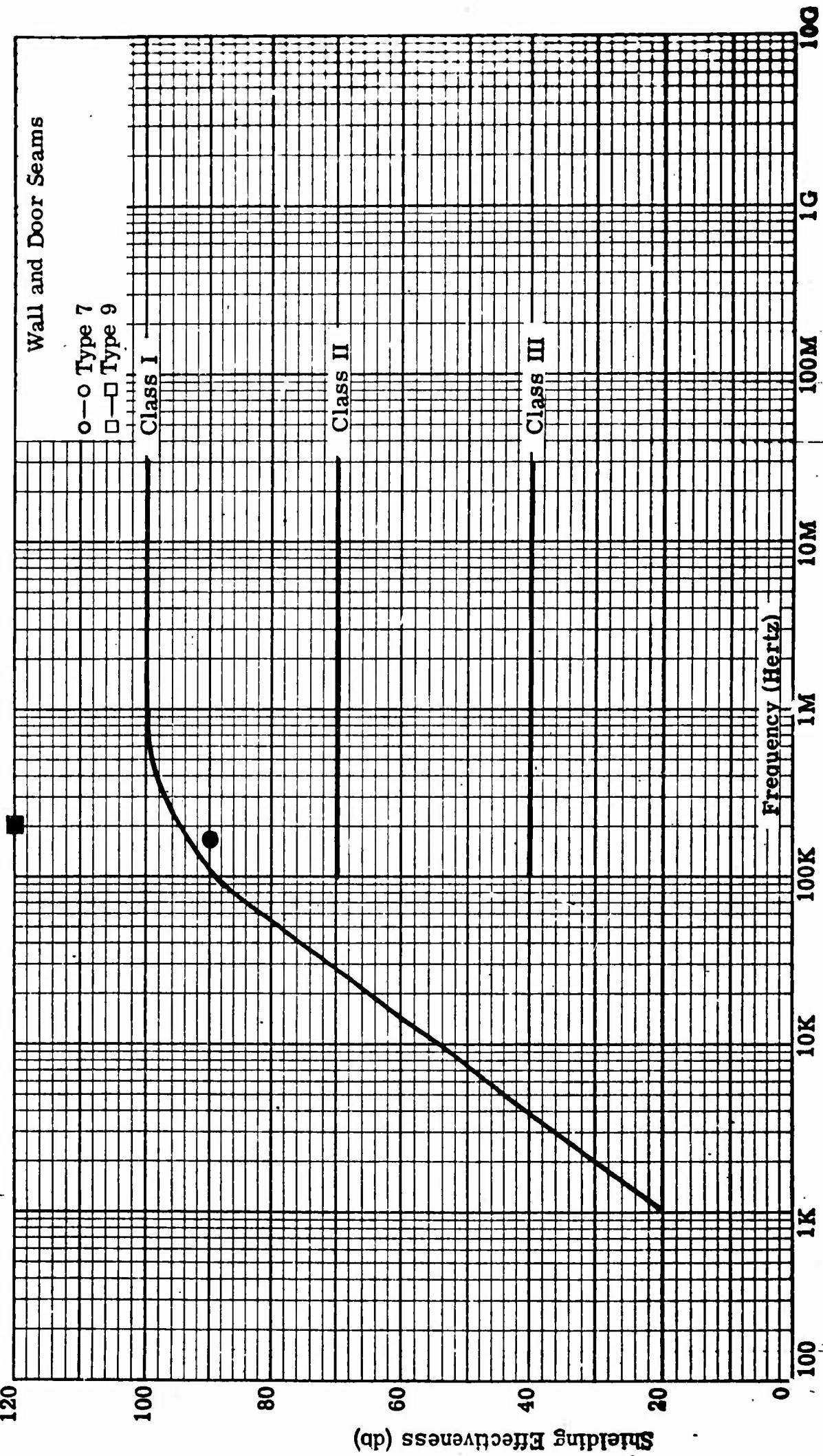


FIGURE 86
MAGNETIC SHIELDING EFFECTIVENESS
FOR IN SITU SEAM TESTING OF NEW SHIELDED FACILITIES

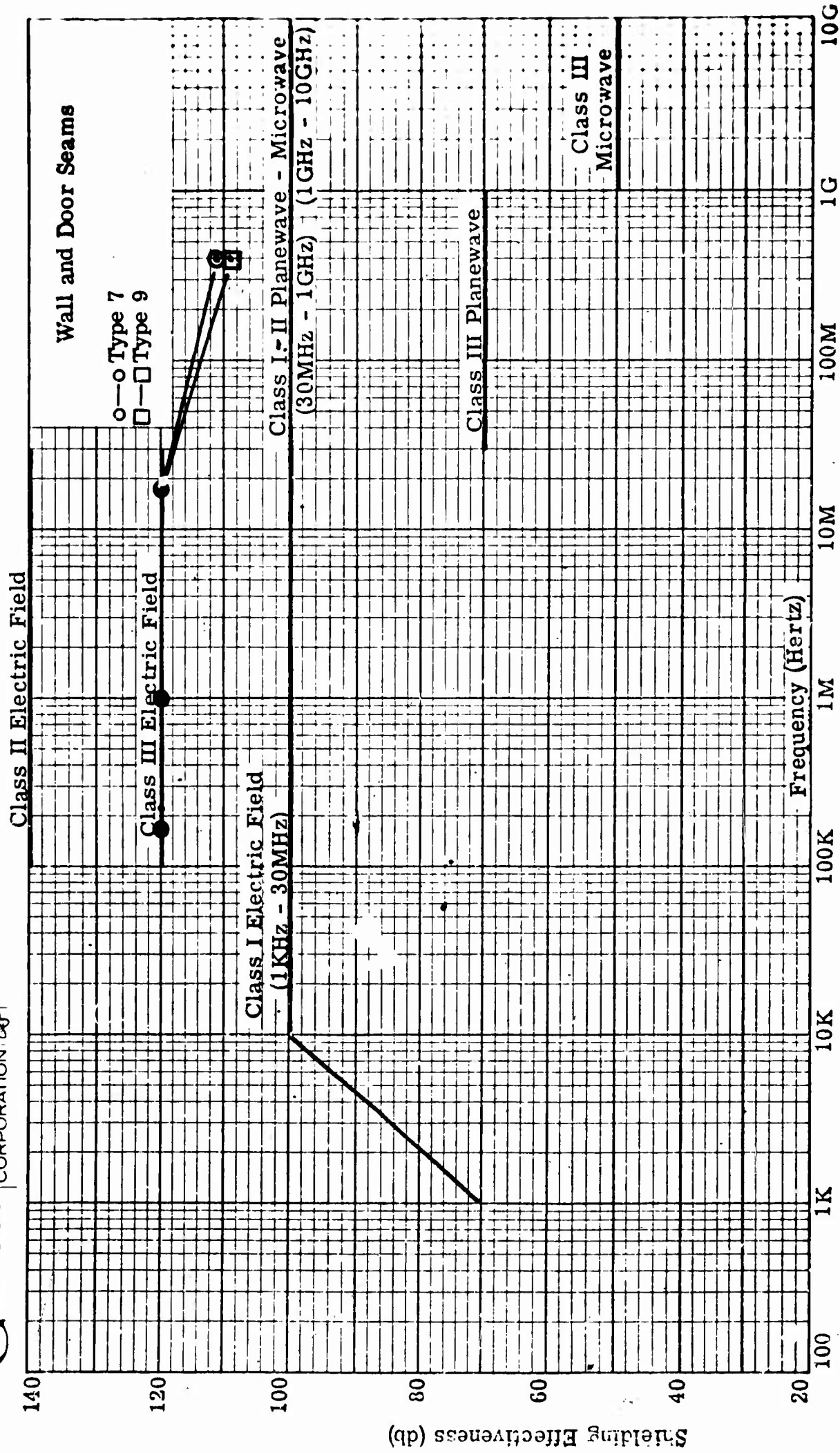


FIGURE 87
SHIELDING EFFECTIVENESS FOR ELECTRIC FIELDS, PLANEWAVES, AND MICROWAVES
FOR IN SITU SEAM TESTING OF NEW SHIELDED FACILITIES

APPENDIX II

CONDUCTIVITY AND PERMEABILITY MEASUREMENTS

INTRODUCTION

This section answers two major questions which have long puzzled shielding designers.

1. Does the permeability of ferrous materials vary with changes in frequency when exposed to a constant level of magnetic fields?
2. Can the shielding effectiveness of ferrous materials be changed under exposure to high magnetic field intensities?

In order to compute the theoretical magnetic shielding effectiveness of ferrous materials it is imperative that their permeability and conductivity be known accurately. It is a near universally accepted fact that the permeability of ferrous materials decreases with frequency. D. Moehring (9) cites the results of such early investigators as Drude, Hagen and Rubens, Arkadiet, and Stienhausen. Each of these indicate that the permeability of ferromagnetic materials decreases with increasing frequency, approaching unity in the centimeter wavelengths. The following values are typical of those commonly circulated for iron:

<u>FREQUENCY (Hz)</u>	<u>μ_r</u>	<u>FREQUENCY (Hz)</u>	<u>μ_r</u>
100	1150	10K	750
1K	1100	1M	350
10K	1050	10M	200

A second, and equally well circulated concept is that the shielding effectiveness of ferrous shields can be materially degraded under exposure to high intensity magnetic fields.

This study shows much of this information to be inaccurate and the prime source of error in computing the shielding effectiveness capabilities of modern ferrous materials.

For the purposes of this study ferrous shielding materials will be classed as being either low, intermediate or high permeability type shields. The effect of frequency on permeability and the effect of high intensity fields on the shielding effectiveness of each general type of material will be discussed.

(mill annealed), Blue Netic S3-6 foil, Special Netic Foil, Primag 90 sheet, and Primag 40 sheet.

The results of testing in Figures 4 and 5 indicates that the permeability of these materials decreases gradually with frequency. A summary of the results of testing are shown below:

<u>FIGURE</u>	<u>MATERIAL TYPE</u>	<u>CONDUCTIVITY</u>	<u>PERMEABILITY</u>
4	Netic S3-6 Foil (mill annealed)	.1263	1000-220
4	Special Netic Foil	.1263	440-125
4	Blue Netic Foil	.1116	570-240
5	Primag 90 Sheet	.0330	780-560
5	Primag 40 Sheet	.0116	1700-1300

When subjected to magnetic field intensities varying between .04 Oersteds and 2 Oersteds the shielding effectiveness of these materials varied approximately 1 to 5 Db.

High Permeability Materials

The materials tested which exhibited high permeabilities were characterized by their higher cost and sensitivity to shock, stress and temperature. They must be carefully annealed and are not generally available in a large variety of sizes or material thickness'. Tests on the primag materials showed that only the foils (.004" thick) and not the sheets (.060" thick) had high permeability characteristics.

The permeability of these materials did vary with frequency, decreasing rapidly at higher frequencies. The results of testing are shown in Figures 4 and 5 and summarized below:

<u>FIGURE</u>	<u>MATERIAL TYPE</u>	<u>CONDUCTIVITY</u>	<u>PERMEABILITY</u>
4	Co-Netic AA Foil	.0304	30,000-3,000
5	Primag 90 Foil	.0330	60,000-5,400
5	Primag 40 Foil	.0116	48,000-1,500

Under exposure to varying field intensities the performance of the Co-Netic AA material was altered from 4 to 10 Db as shown in Figure 12. The performance of Primag 90 Foil was changed approximately 2 to 4 Db as shown in Figure 13.

TEST PROCEDURE FOR MEASURING PERMEABILITY

The permeability of any material can be derived from the absorption loss portion of the shielding effectiveness equations (10) developed by Schelkunoff (11) as shown below:

Low Permeability Materials

Low permeability ferrous materials can generally be described as those materials that are commercially available at reasonable cost in a variety of sheet sizes, shapes or thickness'. Cold rolled steel, hot rolled steel, galvanized steel, terne steel and stainless steel are materials in this class that were evaluated in this study.

The results of testing between 100 Hz and frequencies as high as 3MHz indicate that the permeability of these more standard fabricating materials does not vary appreciably with frequency. The overwhelming majority of the variations appearing in Figures 1 thru 3 are within the accuracy of the measuring instrumentation. There may be some variations from sample to sample, due perhaps to undetectable innate qualities of the metal or environmental conditions during the forming process.

For the purposes of computing theoretical shielding effectiveness of single value for permeability and conductivity will yield quite accurate results. The following tabulation gives suggested values as a result of this study:

<u>FIGURE</u>	<u>MATERIAL TYPE</u>	<u>CONDUCTIVITY</u>	<u>PERMEABILITY</u>
1,3	Cold Rolled Steel	.1576	127
1	Hot Rolled Steel	.1603	160
2	Terne Steel	.1517	157
2	Galvanized Steel	.1766	270
3	Stainless Steel	.0284	227

The approximate average change in shielding effectiveness of low permeability materials, when subjected to magnetic field intensities varying from .04 Oersteds to 2 Oersteds are tabulated below. This data is typical of that measured on many samples of varying thickness.

<u>MATERIAL TYPE</u>	<u>APPROXIMATE VARIATION</u>
Cold Rolled Steel	1 - 3 Db
Hot Rolled Steel	1 - 2 Db
Terne Steel	1 - 3 Db
Galvanized Steel	1 - 5 Db

More detailed results of testing are shown in Figures 10 and 11.

Intermediate Permeability Materials

Intermediate type materials can be described as those not readily available in a variety of sizes, shapes and thickness; more expensive; and probably not requiring elaborate annealing techniques. Materials tested in this class were Netic S3-6 foil

$$\mu_r = A^2 / \sigma_r f t^2 (3.338 \times 10^{-3})^2 \quad (1)$$

where μ_r = Permeability of the test material relative to copper

t = Sample thickness in mills (thousandths of an inch)

f = Test frequency in hertz

r = Conductivity of the test sample relative to copper

A = Absorption losses in Db

In equation (1) t and f (the independent variable) are readily obtained. Conductivity (σ_r) and absorption losses (A) can be measured. When substituted in equation (1) the change of permeability with frequency for any material can be obtained.

Absorption Losses

"A" can be obtained empirically by first measuring the shielding effectiveness of a test sample of thickness (t). Next, repeat the measurement on the same material with a thickness of $2t$. The shielding effectiveness of each sample is:

$$S_1 = A_1 + R_1 + B_1 \text{ for single thickness} \quad (2)$$

$$S_2 = A_2 + R_2 + B_2 = 2A_1 + R_2 + B_2 \text{ for double thickness} \quad (3)$$

where S = Total Shielding Effectiveness to incident magnetic fields

R = The sum of reflection losses occurring at the air-to-metal and metal-to-air interfaces

B = A correction to the reflection loss term due to successive re-reflections within the material when A is low enough to permit these to become significant.

From equation (1) it can be seen that $A_2 = 2A_1$ since only t has been altered in the two tests.

Since all test parameters have remained unaltered $R_1 = R_2$. When $A \ll 4$ Db, $B_1 = B_2$. When equation (2) is subtracted from equation (3) under the above conditions we obtain:

$$A_1 = S_2 - S_1$$

The value of A was obtained using this technique and the test fixture shown in Figure 8 from 100 Hz through 3 MHz for various test samples.

Measuring Electrical Conductivity

The electrical conductivity (σ) of a sheet test sample of known dimensions can be readily obtained by measuring its DC resistance using the test configuration shown in Figure 9. A DC current of 100 amperes causes a millivolt drop to appear across small test samples. By substituting the known data into the following equation conductivity can be obtained.

$$\sigma = I l / V t w = \text{mhos/meter}$$

where w = Test sample width (meters)

t = Test sample thickness (meters)

l = Length between contacts (meters)

Division by the conductivity of copper (5.9772×10^7 mhos/meter) yields relative conductivity (σ_r) of the test sample.

ERRONEOUS DATA

Sources of leakage around the plane panel shield cause "apparent saturation" affects and the accompanying apparent loss of permeability at high frequencies to appear. This occurs when the penetration signal (through the shield) is reduced below the level of the leakage signal around the shield. At this point the shielding effectiveness curve deviates from a smooth increase with frequency. This can be observed above 2 KHz on the $t = .180$ " curve in Figure 6. As the material thickness is increased this affect will occur at lower frequencies. When testing this samples (such as the .007 inch sample) a lower dynamic range for instrumentation is required and the leakage limitation is pushed out beyond 250 KHz.

Surface conductivity is a very important factor affecting leakage. Most materials are supplied with oiled surfaces and in the case of hot rolled steel and the Blue Netic material a hard oxide coating. Materials must be sand blasted and degreased prior to testing so that an excellent surface to surface contact is insured at the outer rim of the test fixture (see Figure 8). It is this contact which reduces leakage around the shield.

A second natural limitation occurs when sample surfaces are rough, such as with wrought iron. The degrading leakage signal can pass through gaps between the test fixture rims (milled to a flatness of .001") and the rough surface. Most measured data on wrought iron shows the apparent saturation affect which really is due to leakage.

In summary when testing .090" to .180" thickness (see Figure 7) permeability appeared to drop above 2 KHz. Tests on the .024" to .048" sheets extended useful data to 20 KHz where limited dynamic range caused a second limitation. Test on the .007" to .047" sheet extended useful data to 250 KHz. The average permeability on all three sheets (ignoring erroneous data) was 127.06 for 33 measured data points between 100 Hz and 250 KHz.

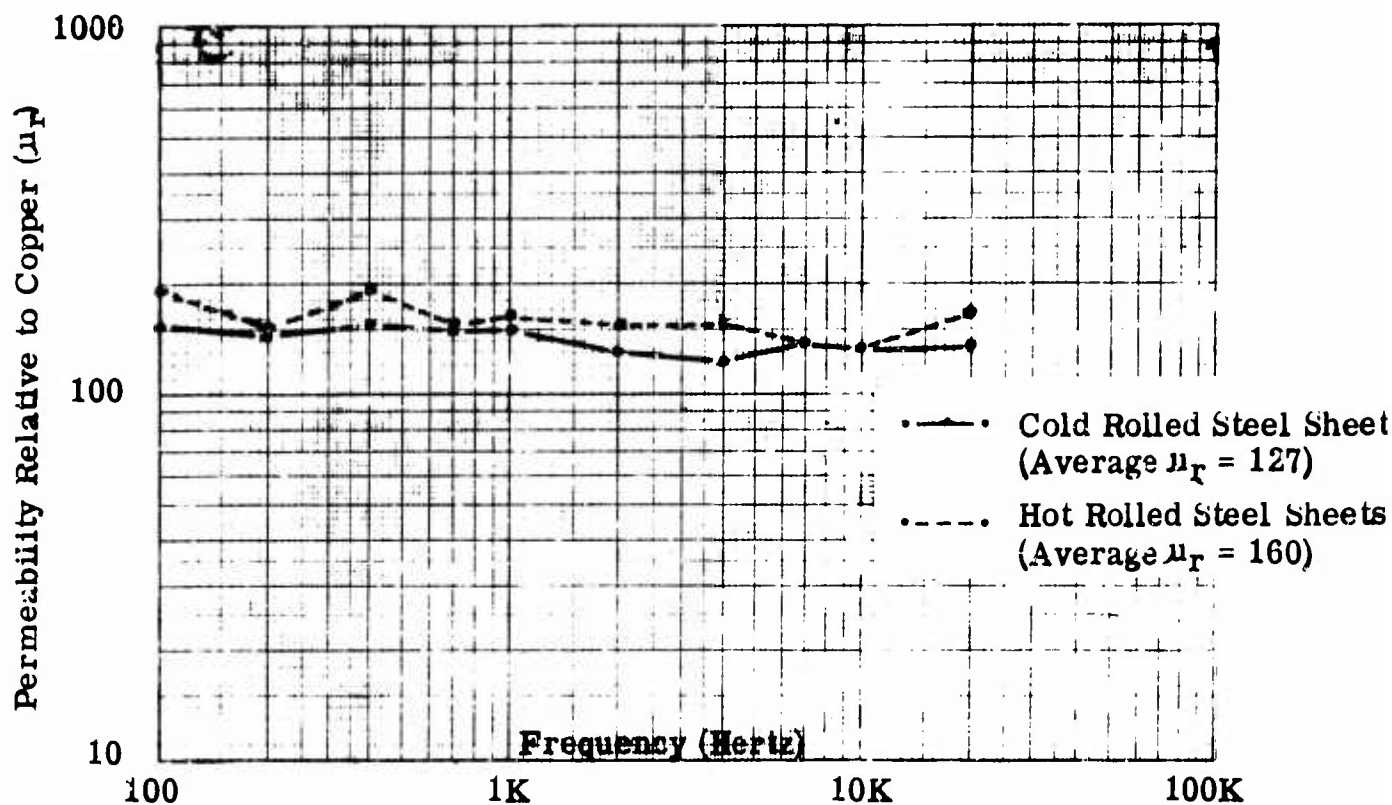


FIGURE 1 PERMEABILITY OF COLD & HOT ROLLED STEEL SHEETS (Thickness $> .020$ "

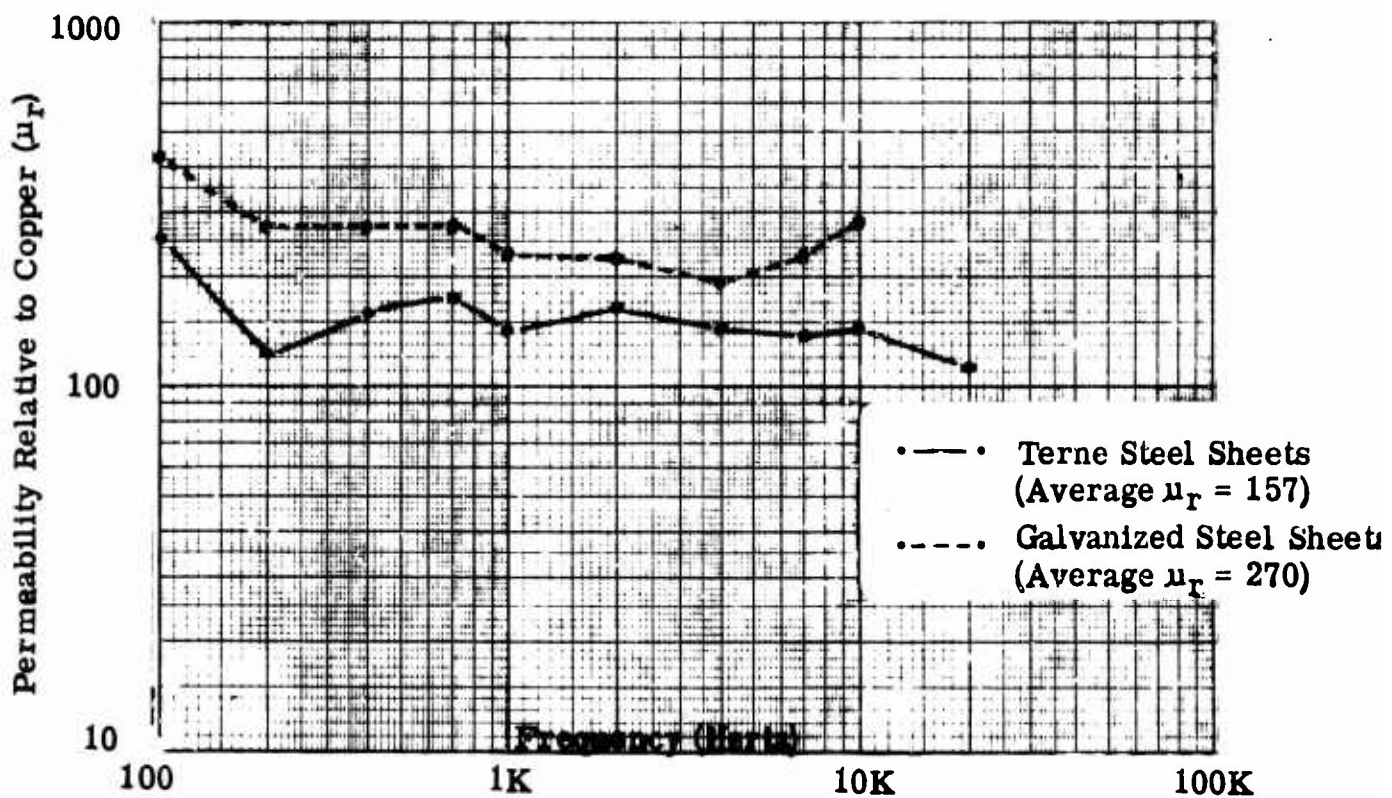


FIGURE 2 PERMEABILITY OF TERNE & GALVANIZED STEEL SHEETS (Thickness $> .020$ "

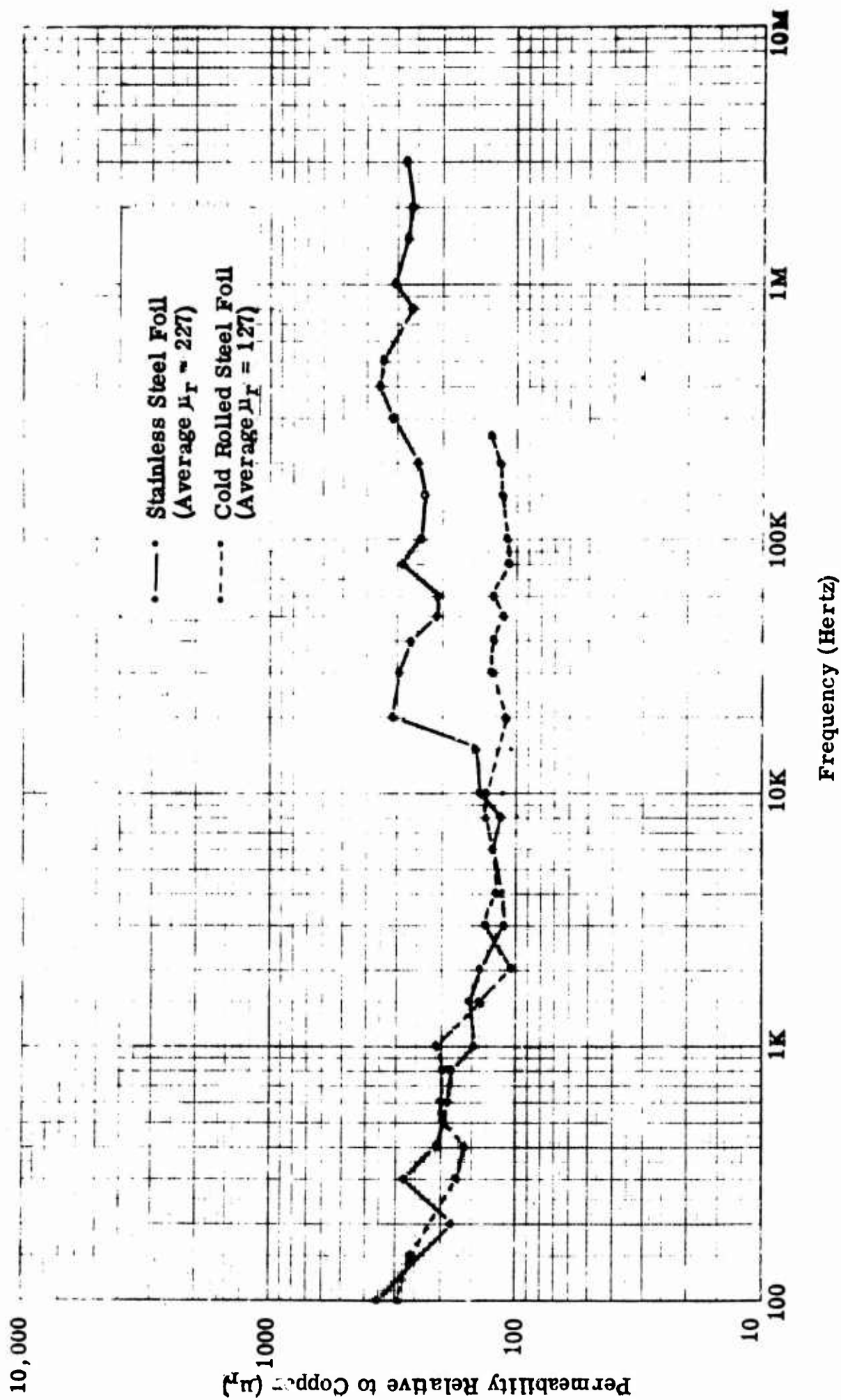


FIGURE 3 RELATIVE PERMEABILITY OF COLD ROLLED STEEL FOIL & STAINLESS STEEL FOIL (Thickness $\approx .015''$)

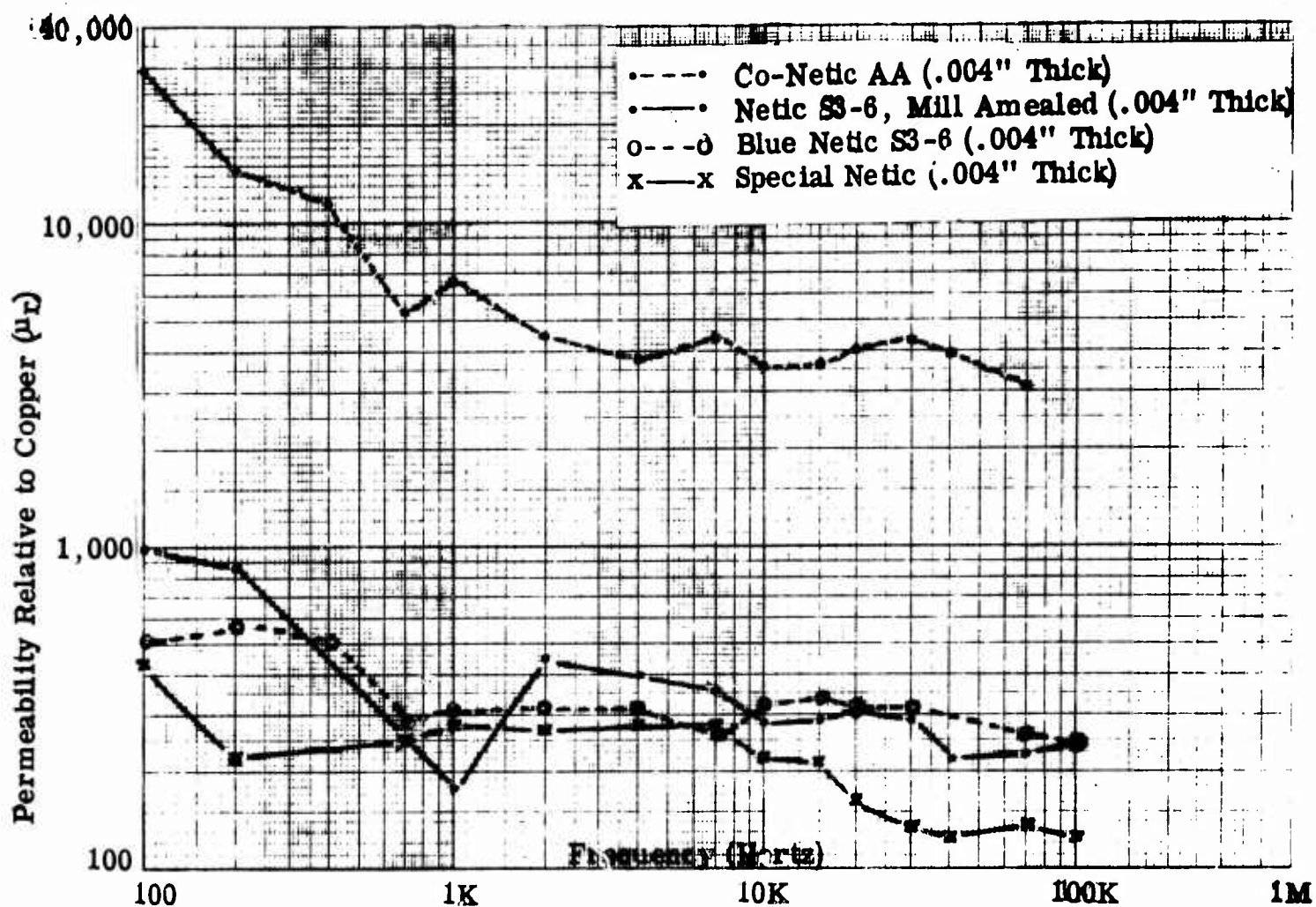


FIGURE 4 PERMEABILITY OF NETIC & CO-NETIC FOILS

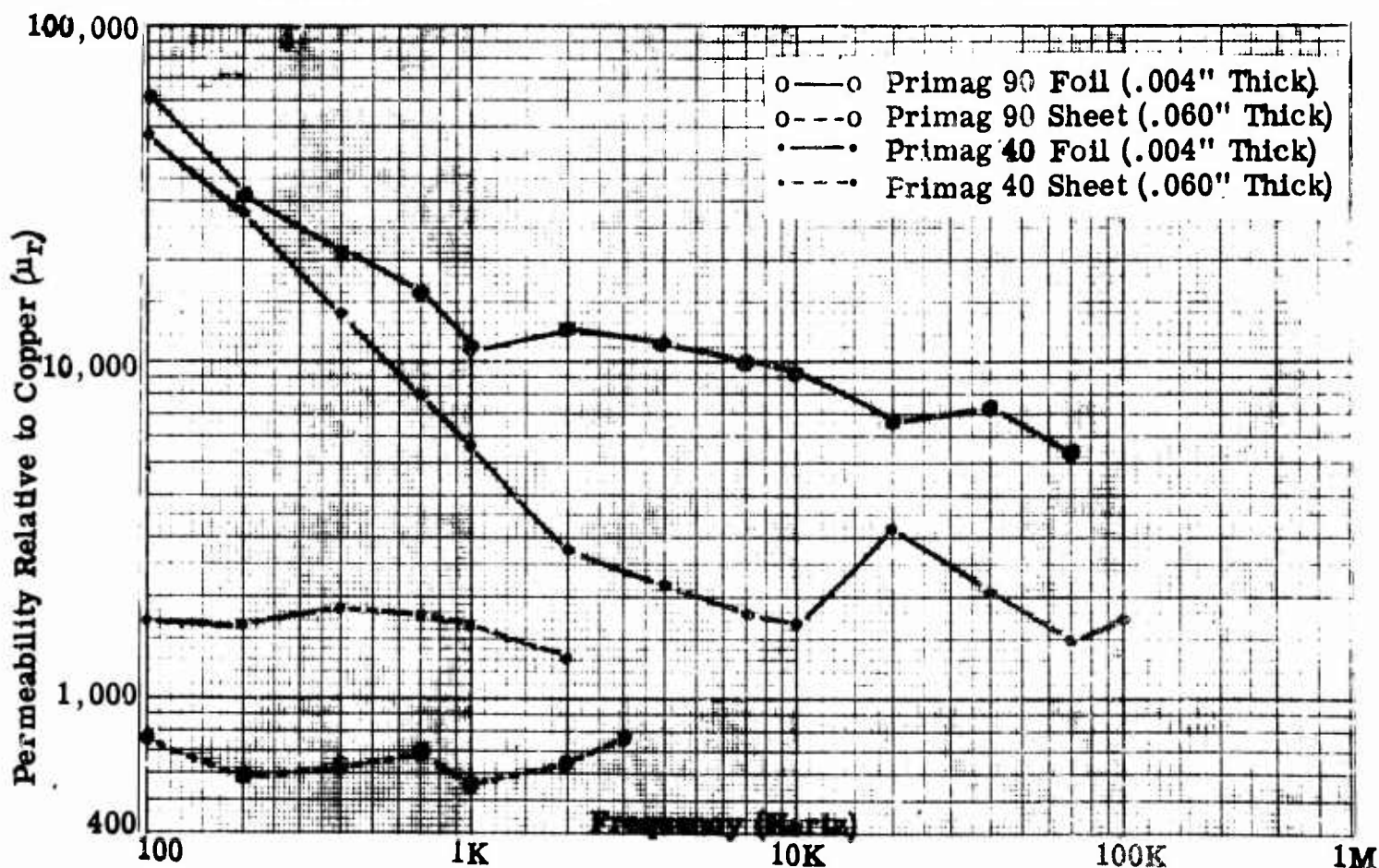


FIGURE 5 PERMEABILITY OF PRIMAG SHEETS & FOILS

FIGURE 7 PERMEABILITY OF COLD ROLLED STEEL FOR VARYING METAL THICKNESS*

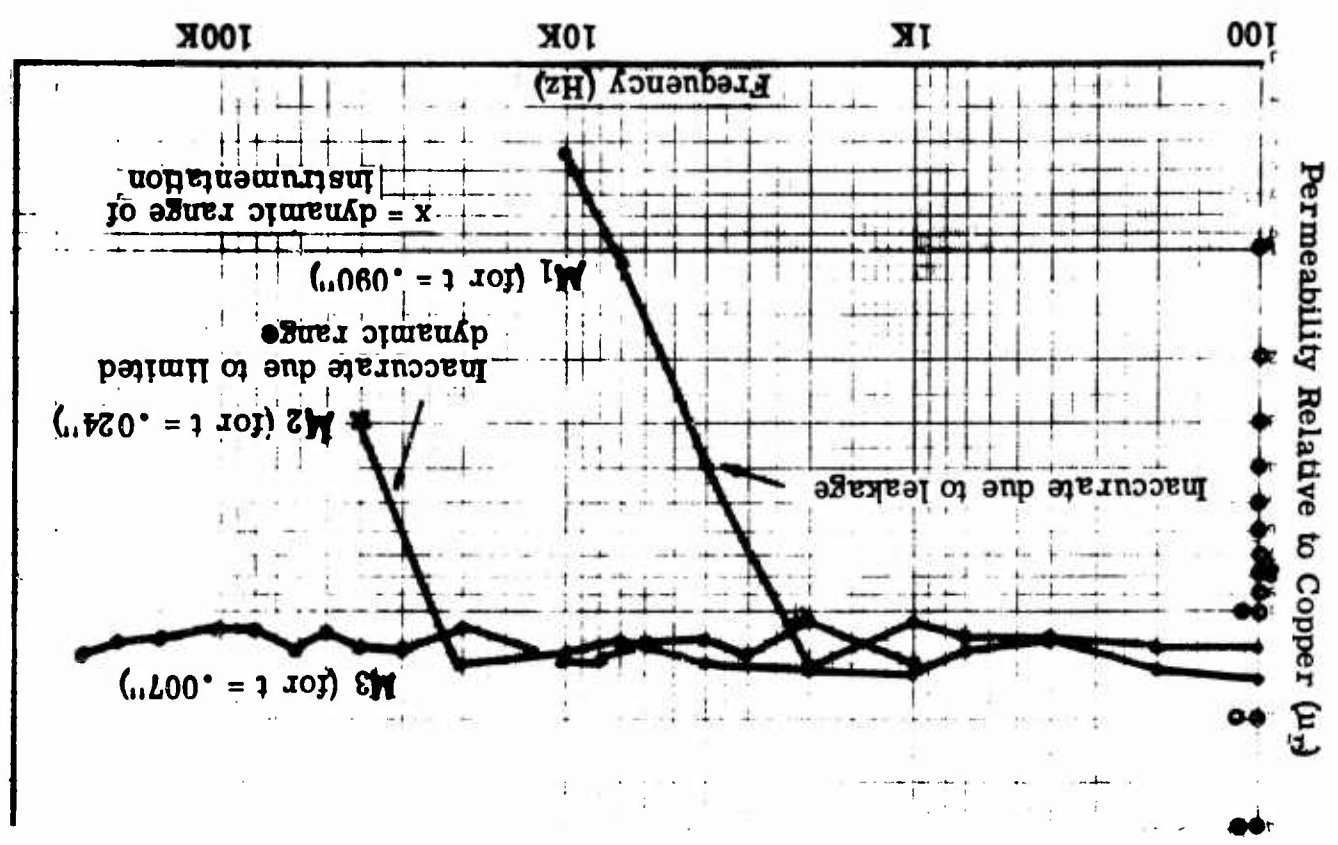
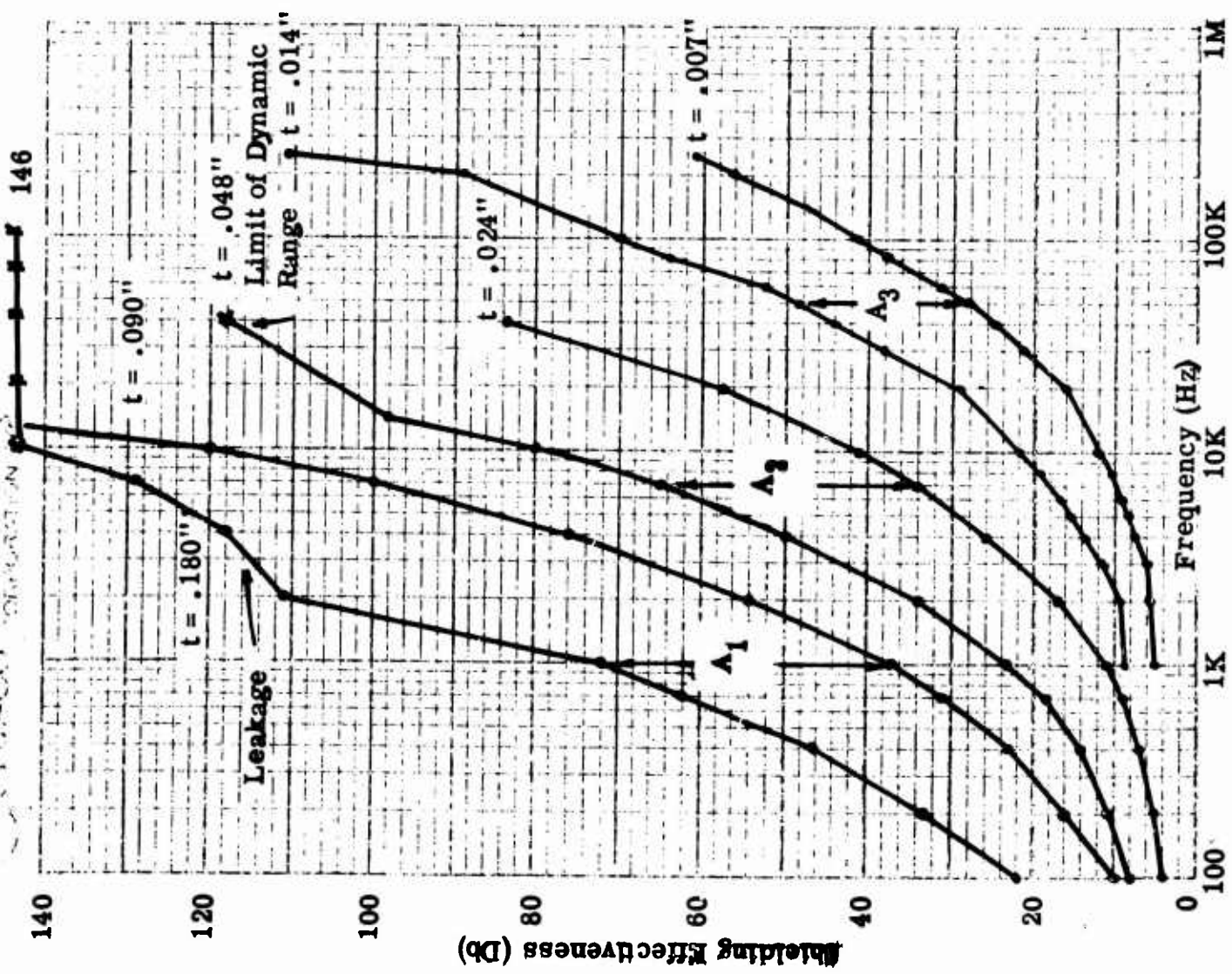


FIGURE 6 MAGNETIC SHIELDING EFFECTIVENESS OF COLD ROLLED STEEL



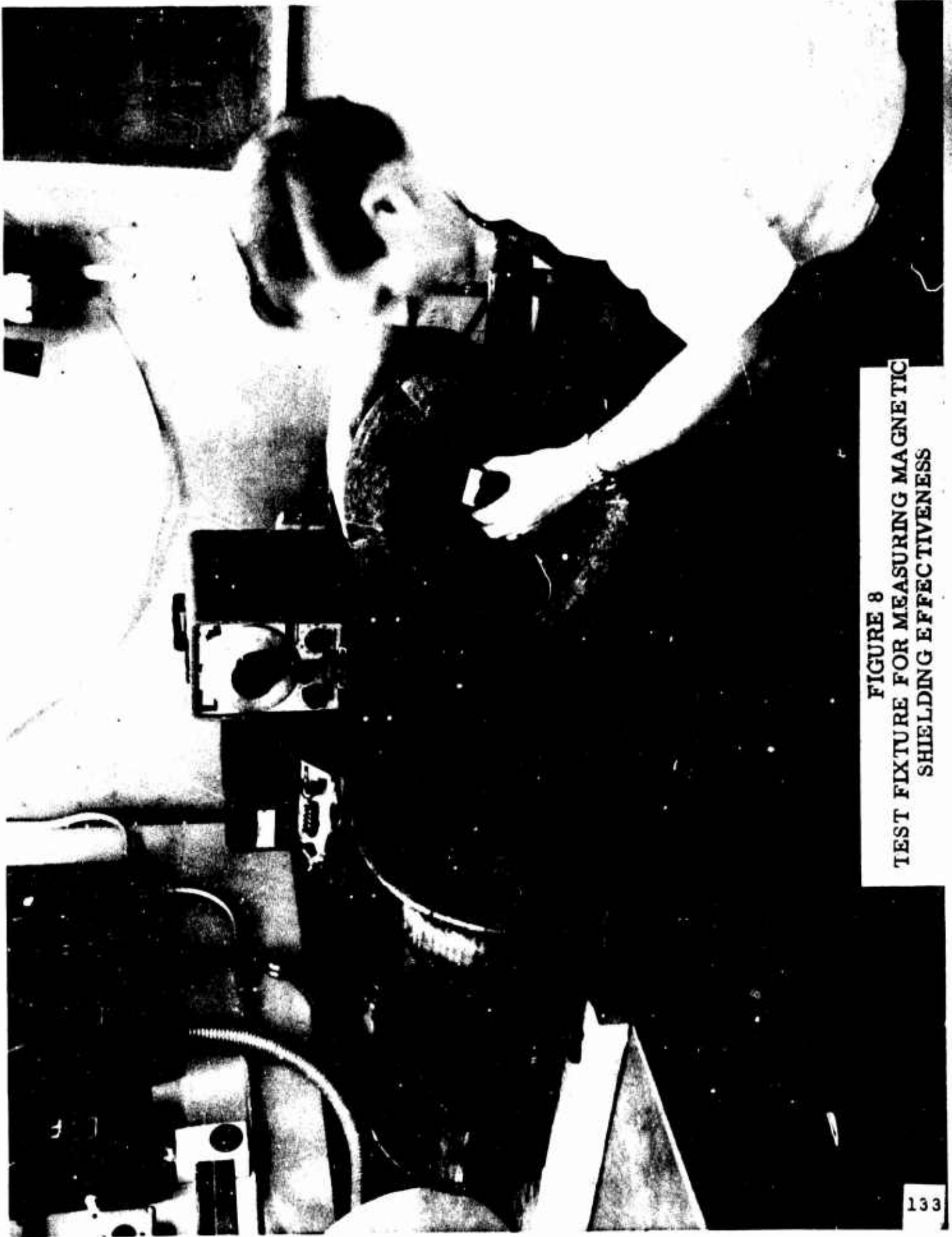


FIGURE 8
TEST FIXTURE FOR MEASURING MAGNETIC
SHIELDING EFFECTIVENESS

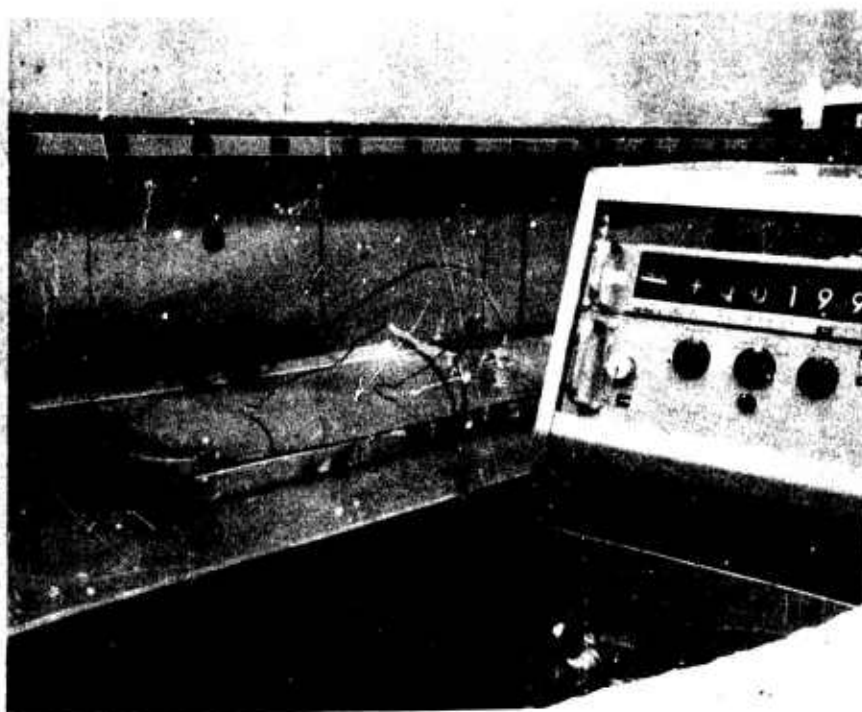
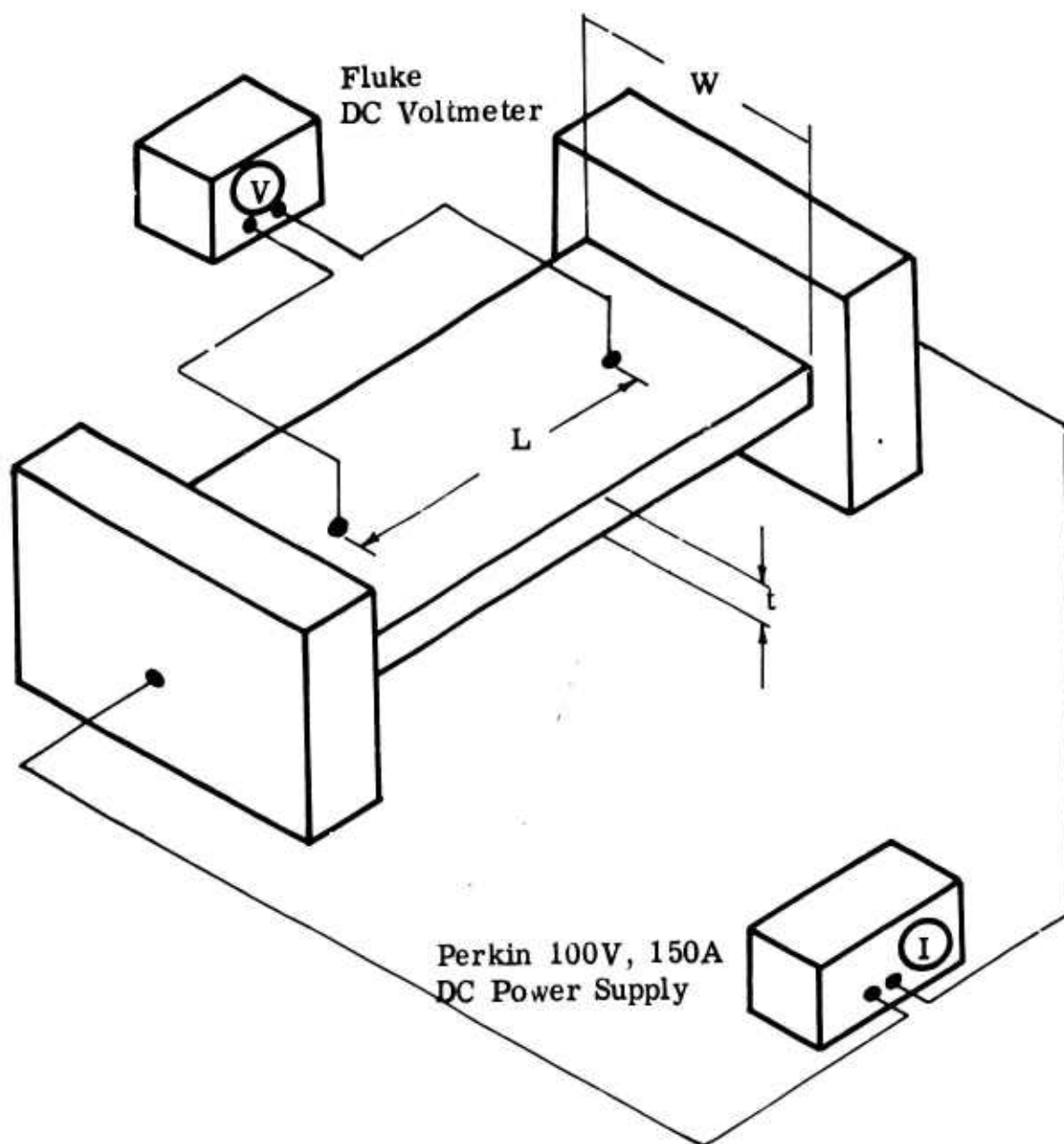


FIGURE 9

TEST CONFIGURATION FOR CONDUCTIVITY MEASUREMENT

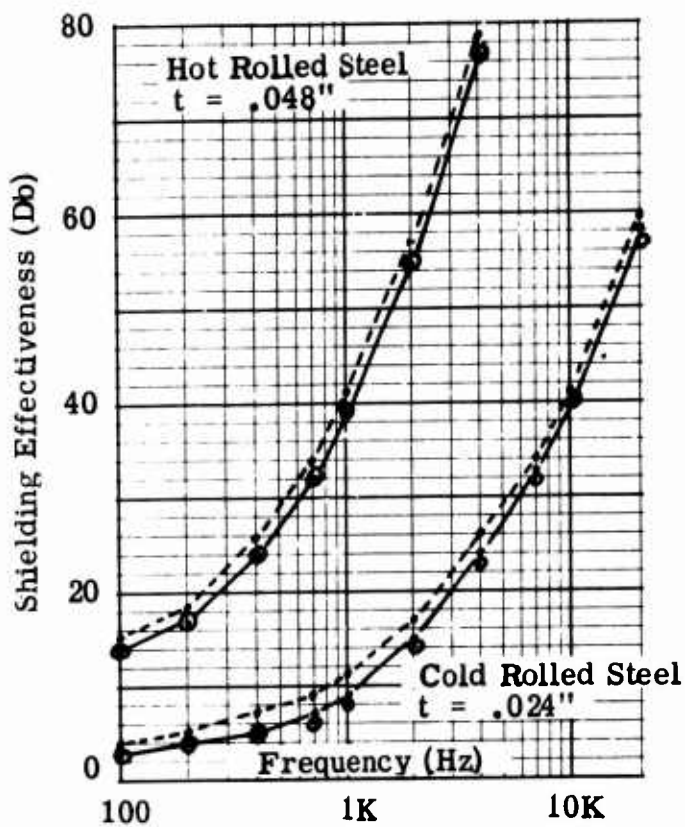


FIGURE 10

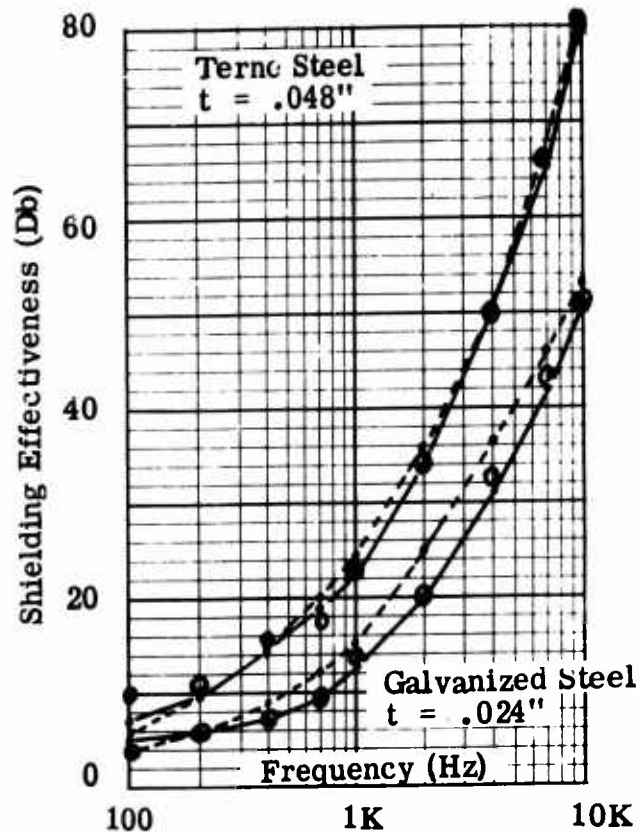


FIGURE 11

Key to Magnetic Field Intensity

- H = 2 Oersteds
- H = .4 Oersted
- o o o H = .04 Oersted

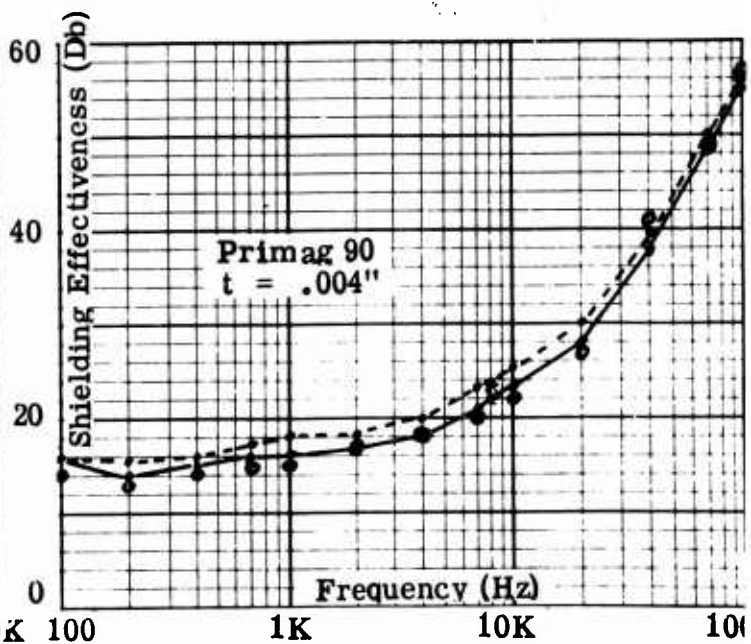
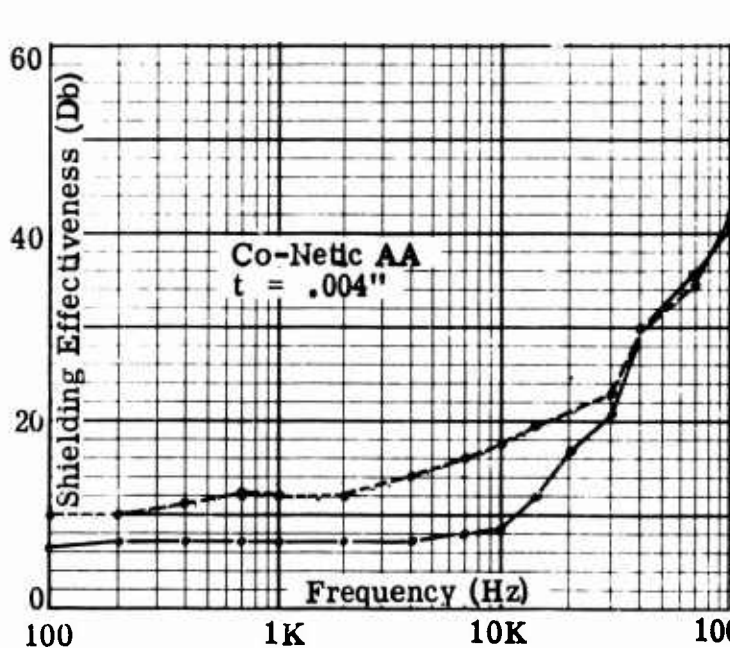


FIGURE 12 SATURATION EFFECT OF HIGH INTENSITY MAGNETIC FIELDS ON FLAT SHEET
(Test Distance = 2 Inches)

APPENDIX III

PORTABLE ENCLOSURE CONCEPTUAL DESIGNS

Contents

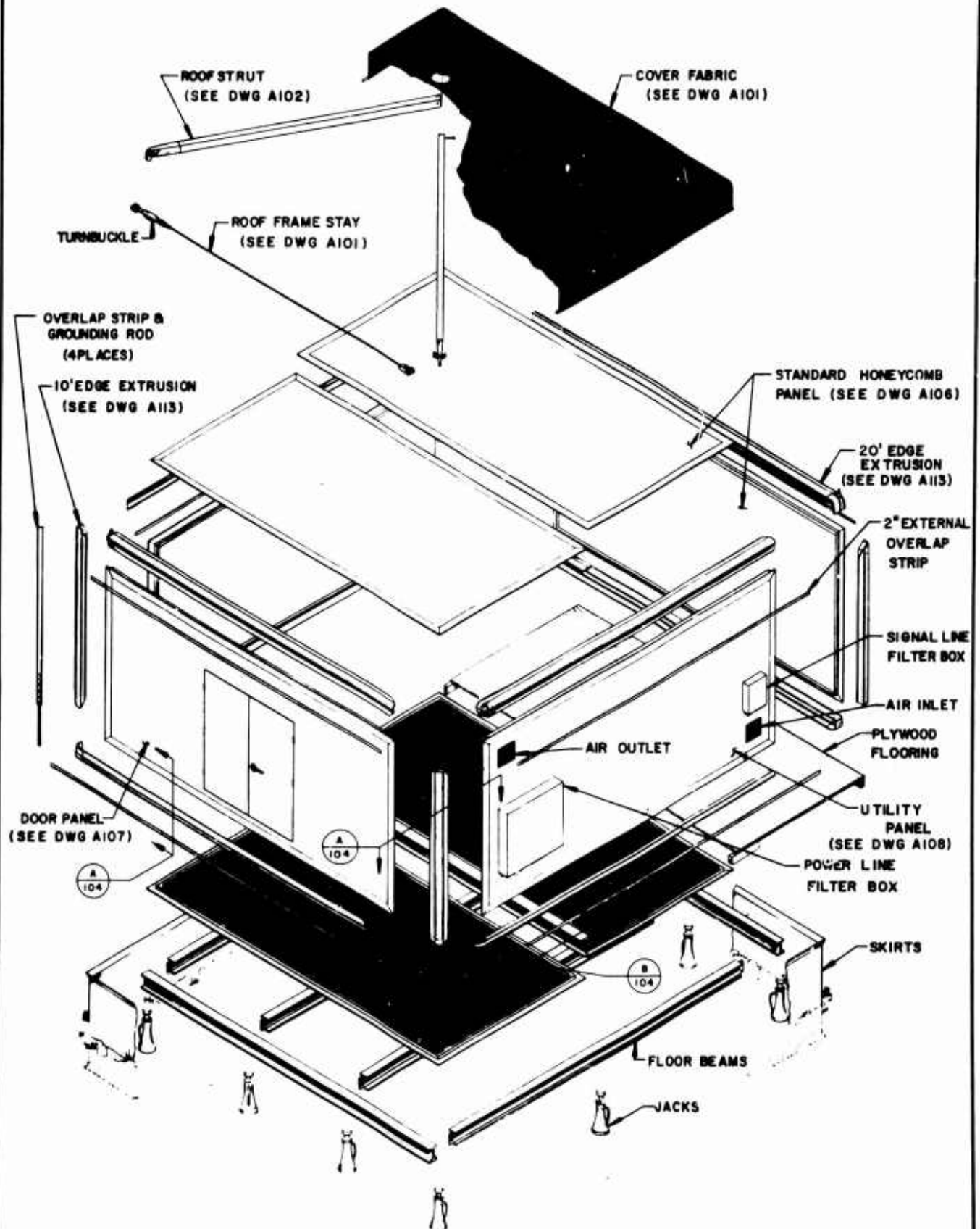
Section A	Conceptual Design Drawings
Section B	Specification References - Materials and Fabrication Notes
Section C	Specification References - Structural Design Calculations
	Design Nomenclature

Note: The calculations presented in Section C are intended to provide design data for future design efforts and demonstrate conformance with the structural requirements for the enclosure. Initial design calculations were made to determine material parameters (i.e., thickness, required yields, etc.). Successive analysis during the design effort resulted in the current conceptual design.



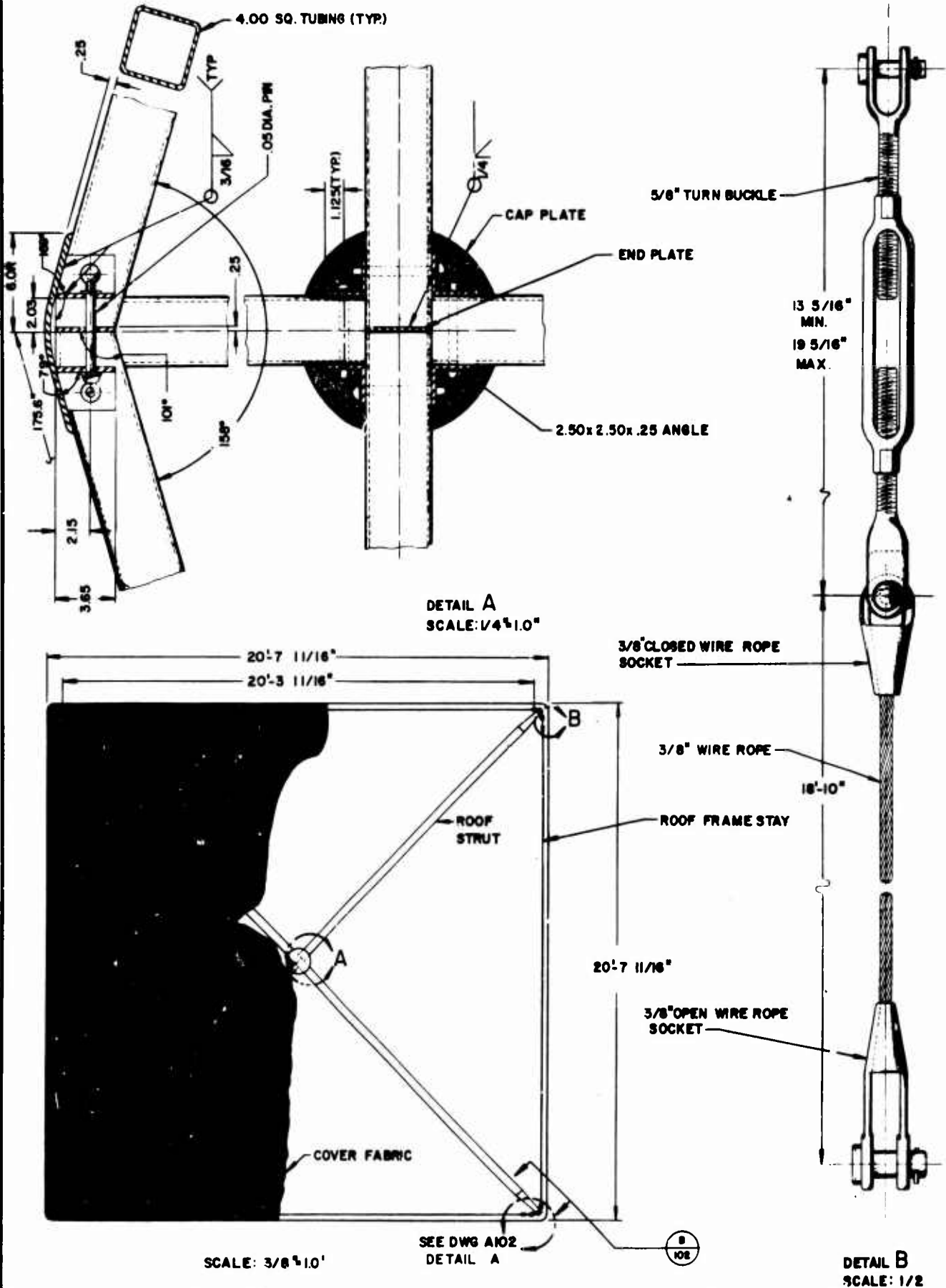
CLASS I AND CLASS II 20'x20'x10'
SHIELDED ENCLOSURE ASSEMBLY

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		1/16	.0005



**CLASS I & II
WEATHER PROTECTION ROOF**

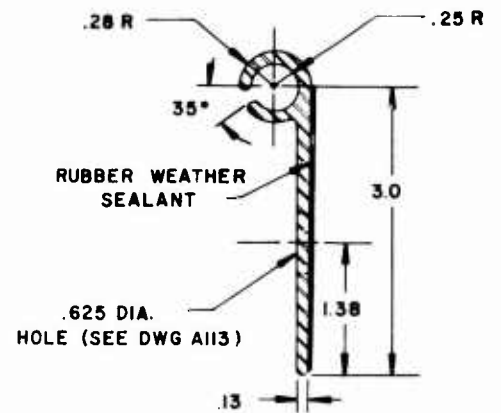
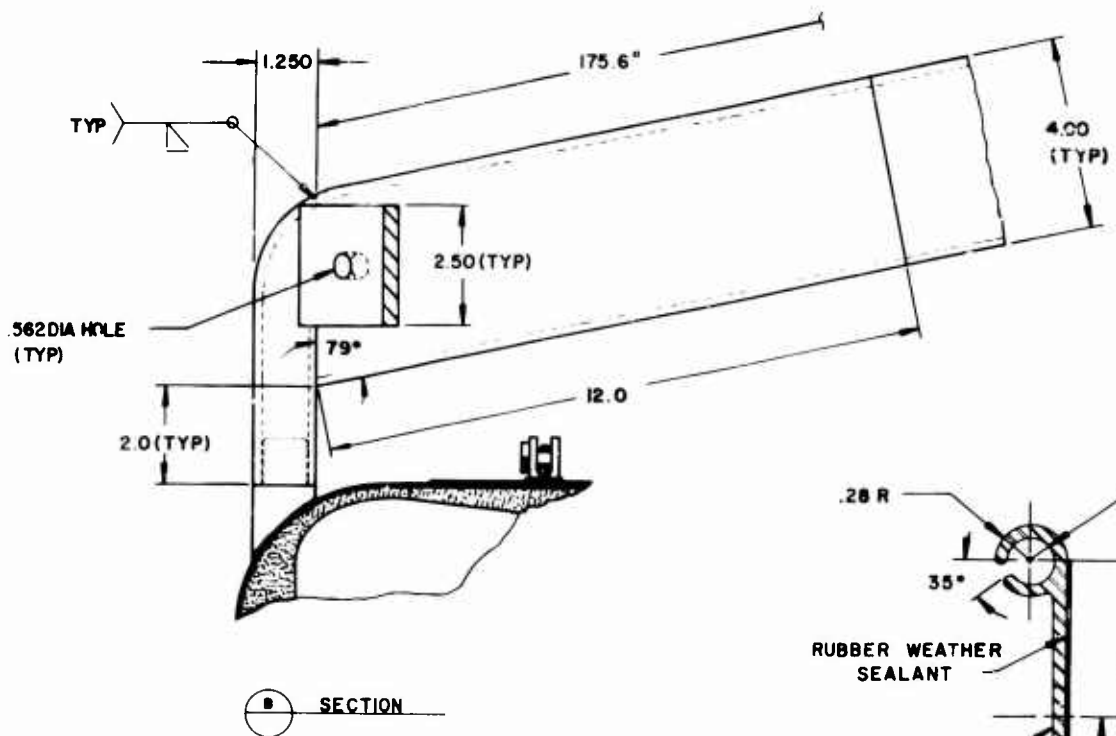
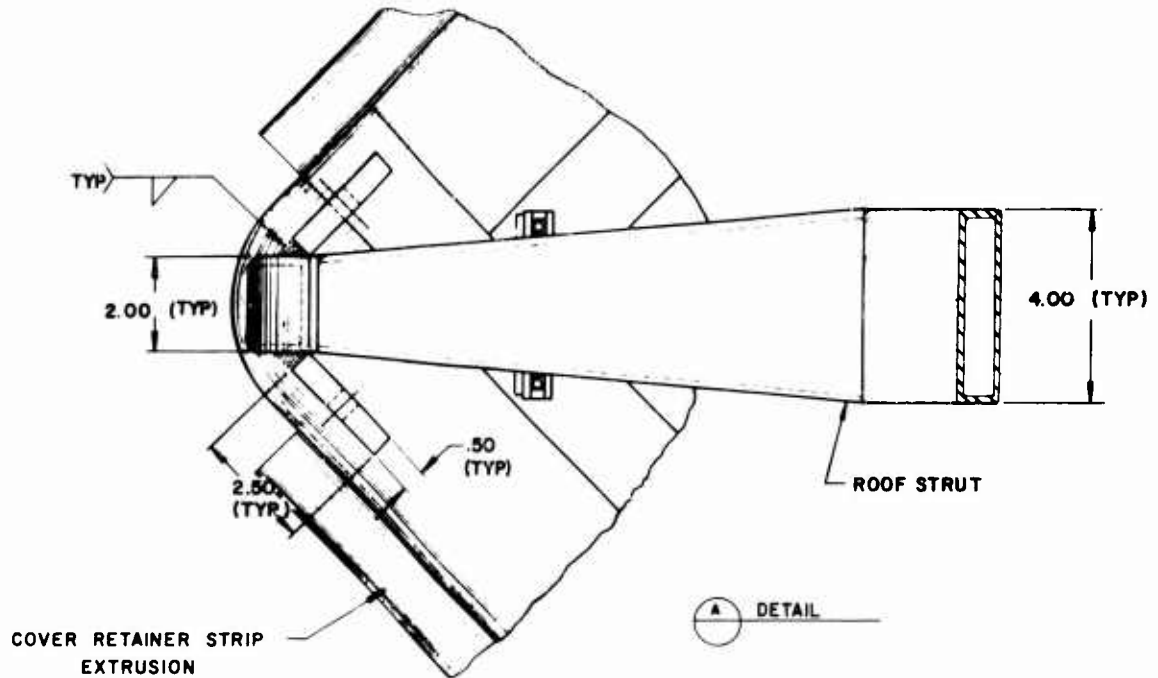
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REVISION			
BY: A; B2.4; C1A			
DATE: 1/18	BY: A; B2.4; C1A	DATE: 1/18	BY: A; B2.4; C1A





MOUNTING AND JOINT DETAIL FOR
WEATHER PROTECTION ROOF

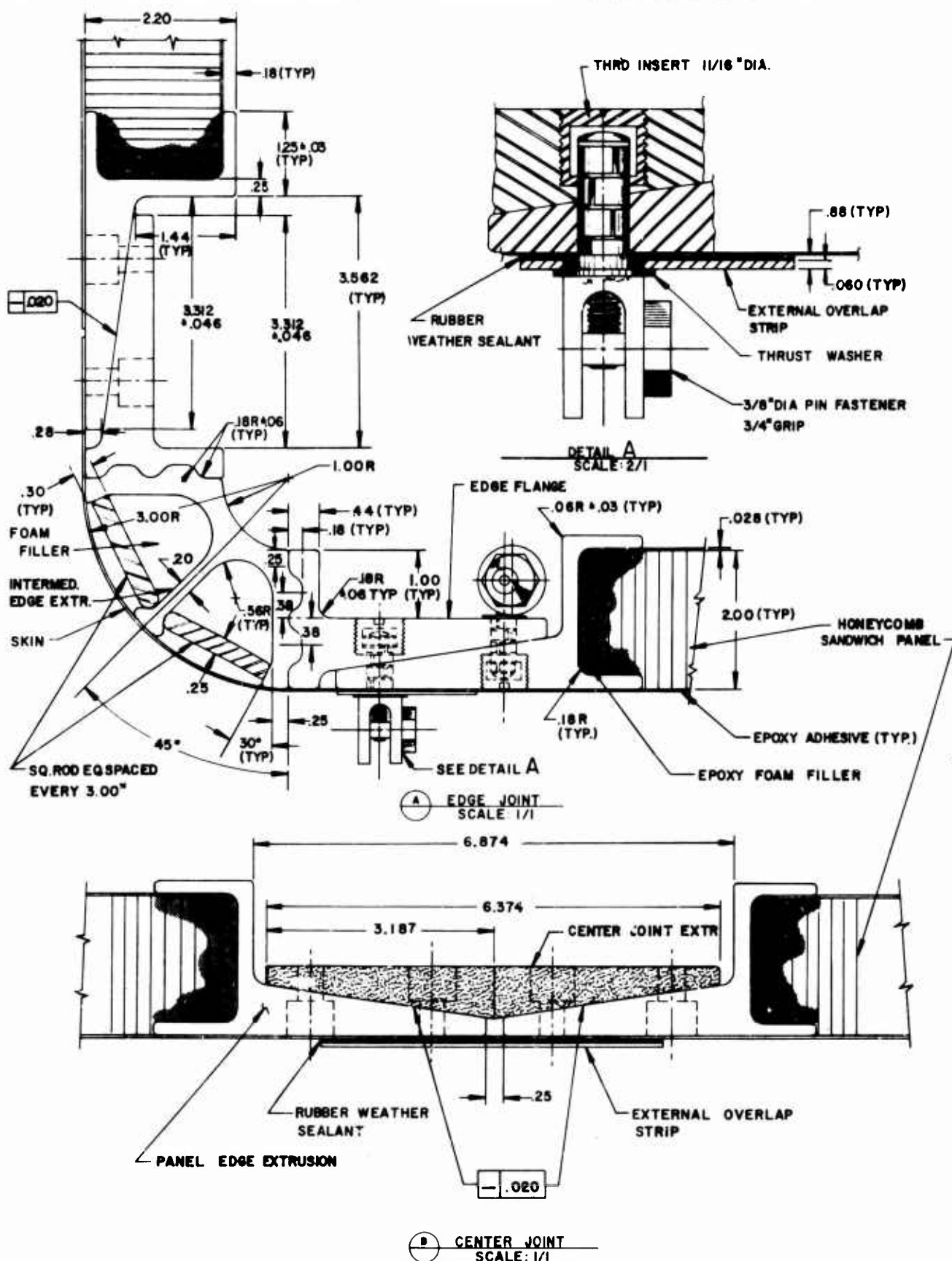
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C COVER RETAINER EXTR.
SCALE: 1/1



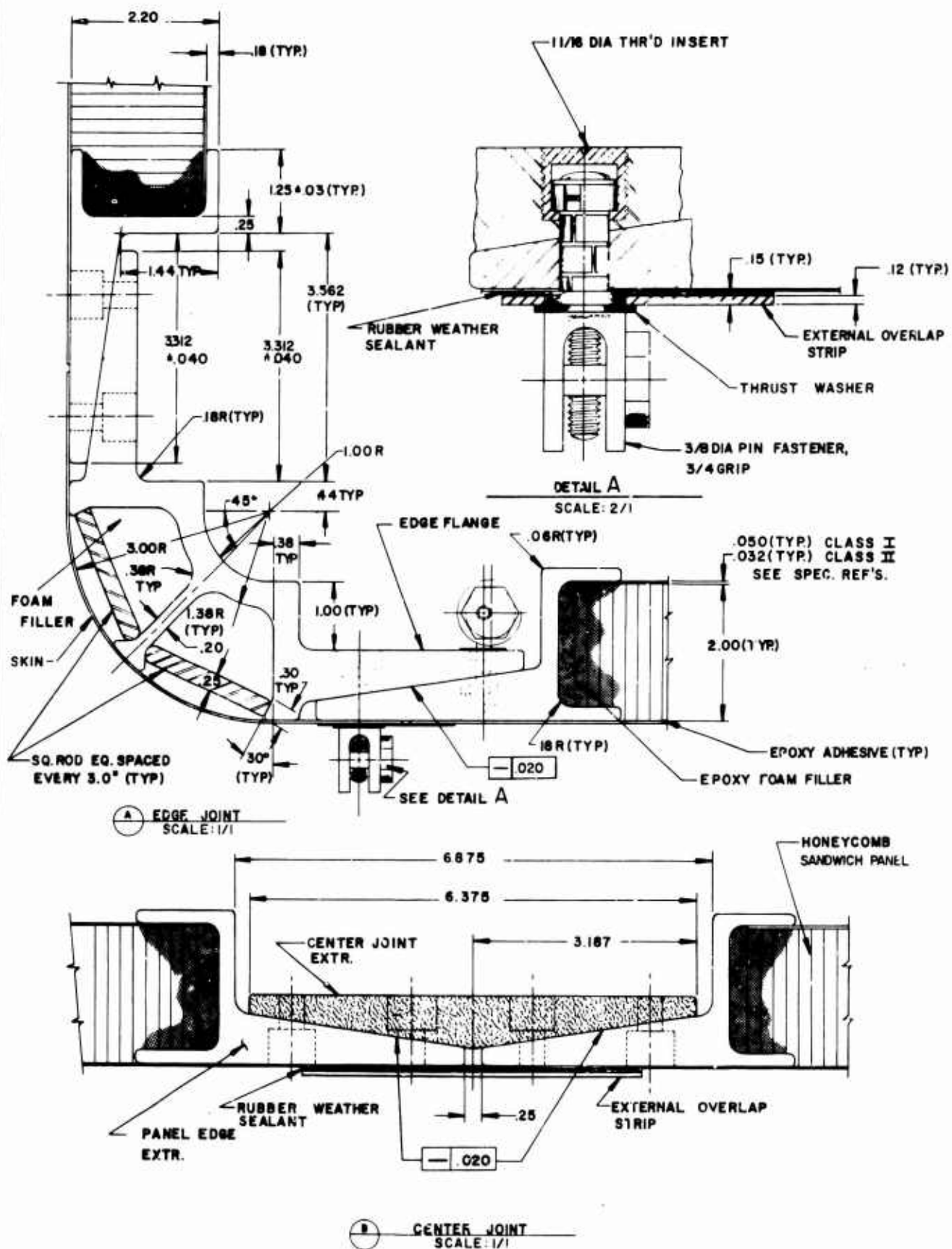
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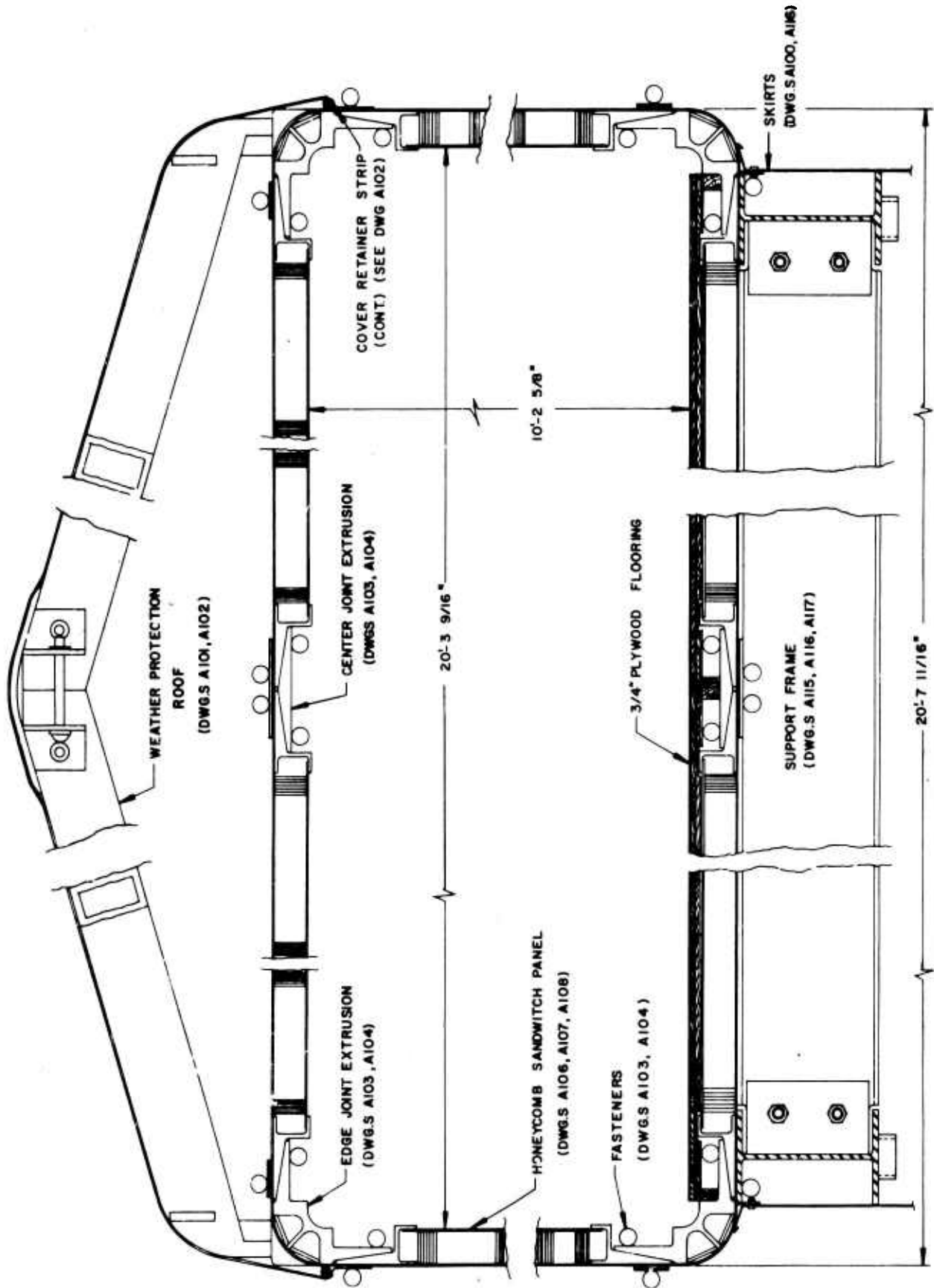




CLASS II EDGE AND CENTER JOINT
DETAIL - EXTRUSIONS & FASTENERS

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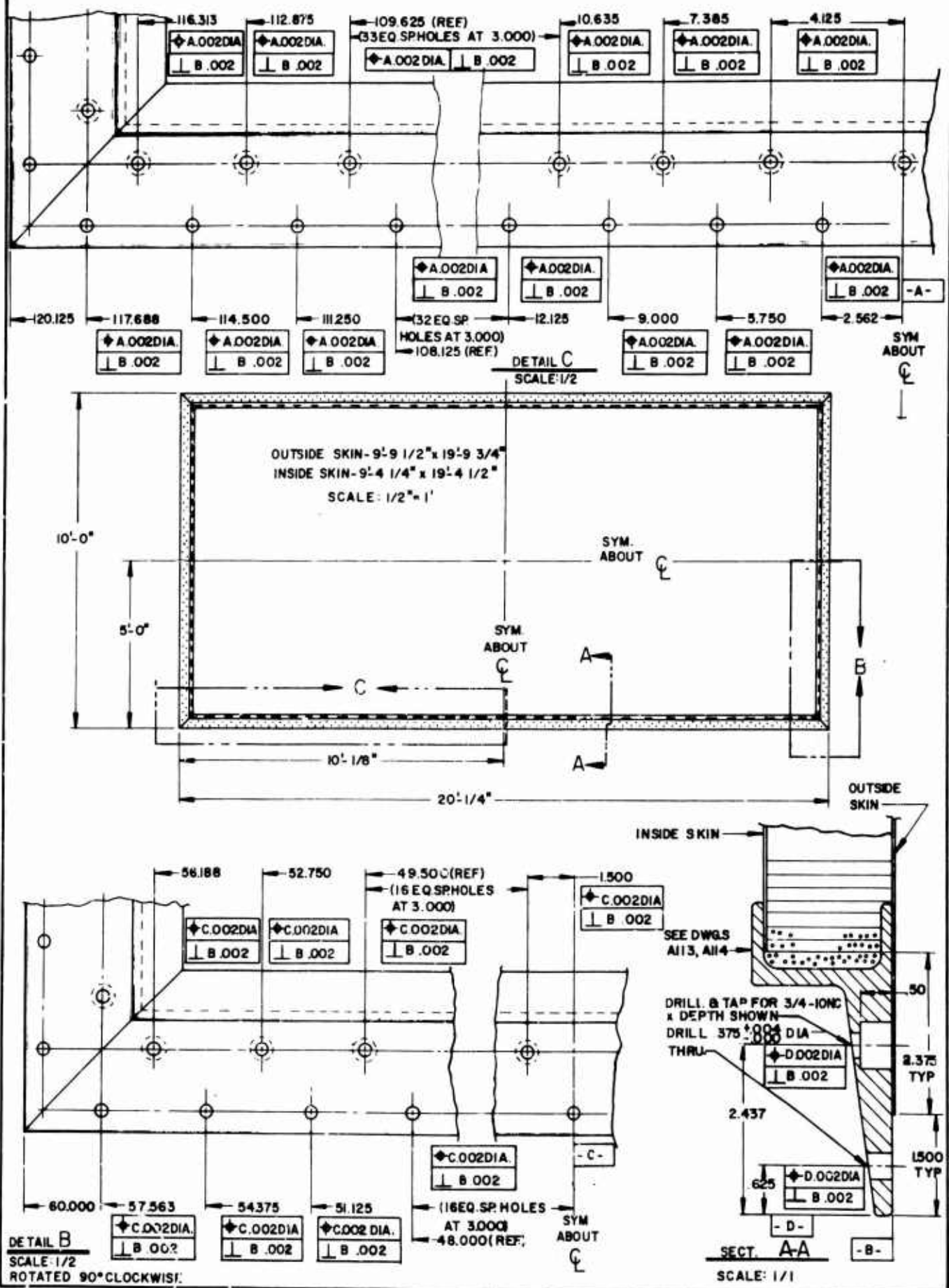






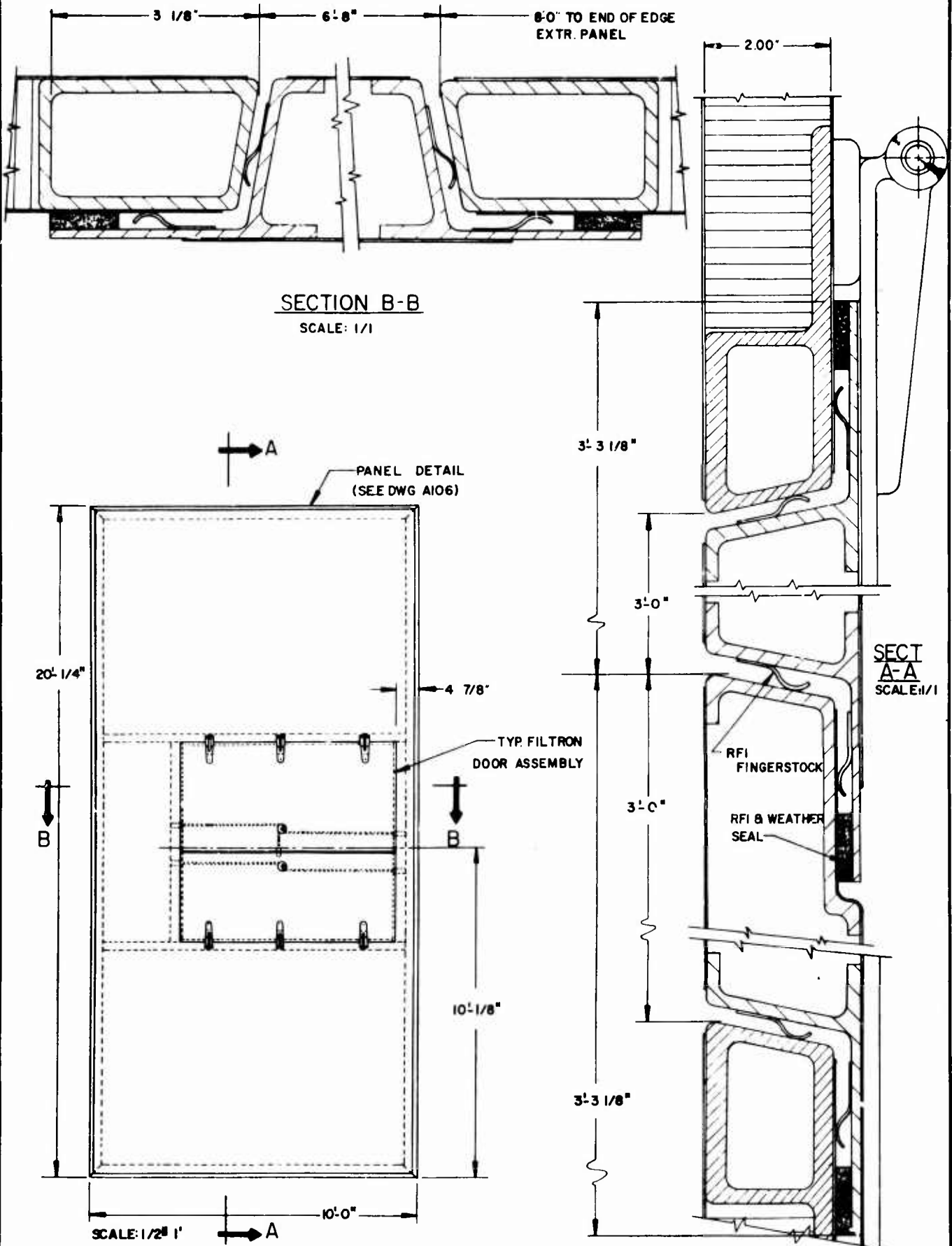
CLASS I & II STANDARD PANEL DETAIL

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**CLASS I & II
DOOR PANEL DETAIL**

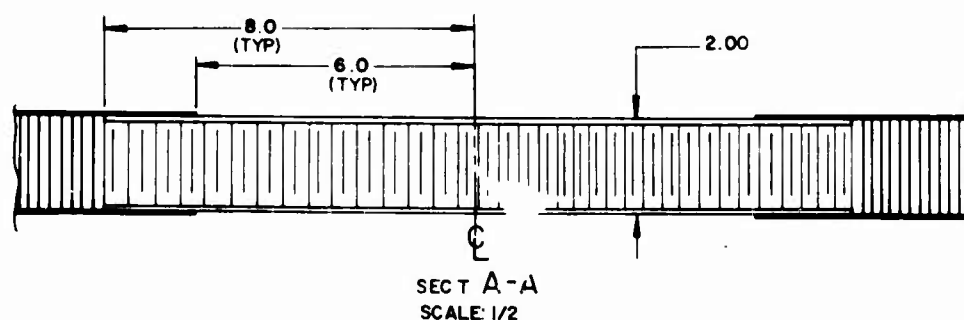
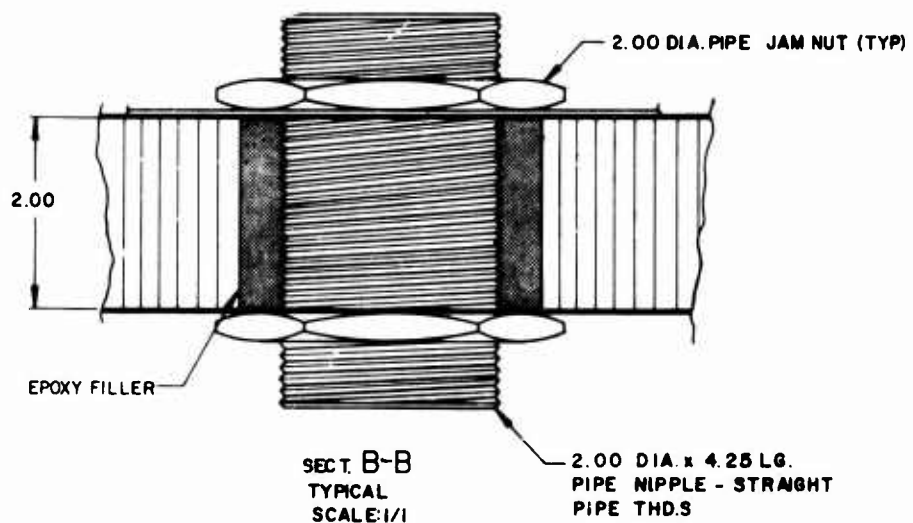
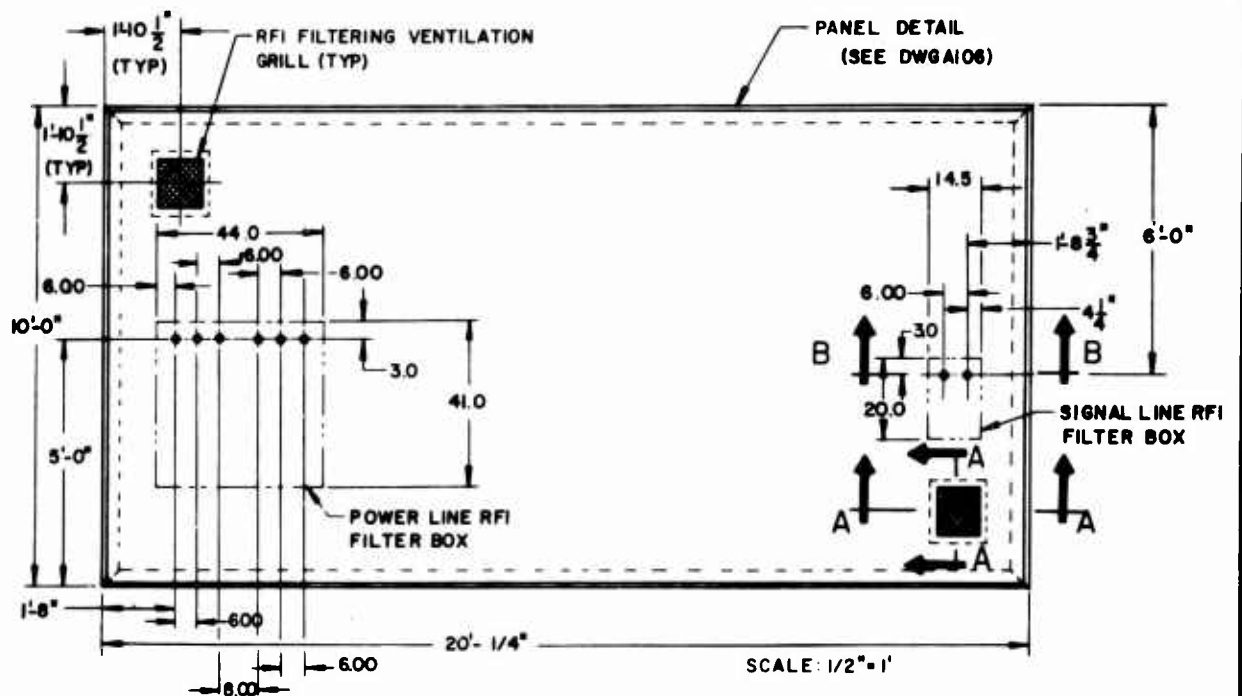
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SPECIFICATION REFERENCE B1.1, B2.1, C1.1	TOL. UNLESS OTHERWISE SPEC.		
	FRAC.	DECIMALS	MILS.
	1/16	0.0625	0.0156
	1/8	0.125	0.0312
	3/16	0.1875	0.0469
	1/4	0.25	0.0625
	5/16	0.3125	0.0781
	3/8	0.375	0.0938
	7/16	0.4375	0.1094
	1/2	0.5	0.125





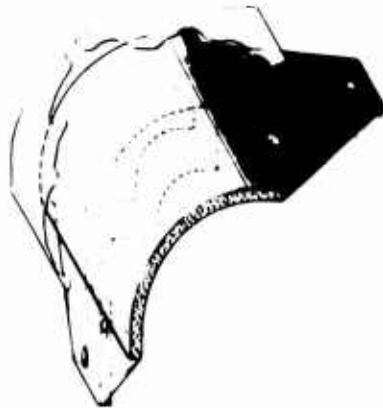
CLASS I & II
UTILITY PANEL DETAIL

SCALE	DRAWING NO.	SHEET
NOTED	10740-A108	9 28
SPECIFICATION REFERENCE:		TOL. UNLESS OTHERWISE SPEC.
B1.1; B2.1; C1.1		
FRAC.	DECIMALS	MILS
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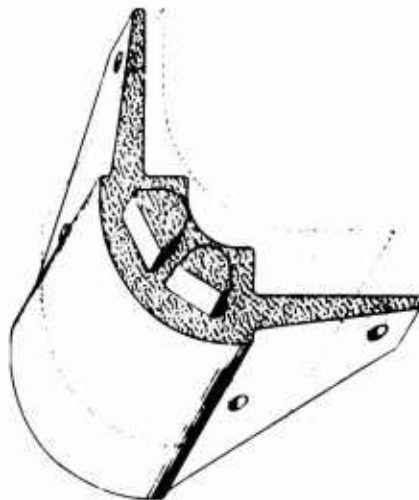
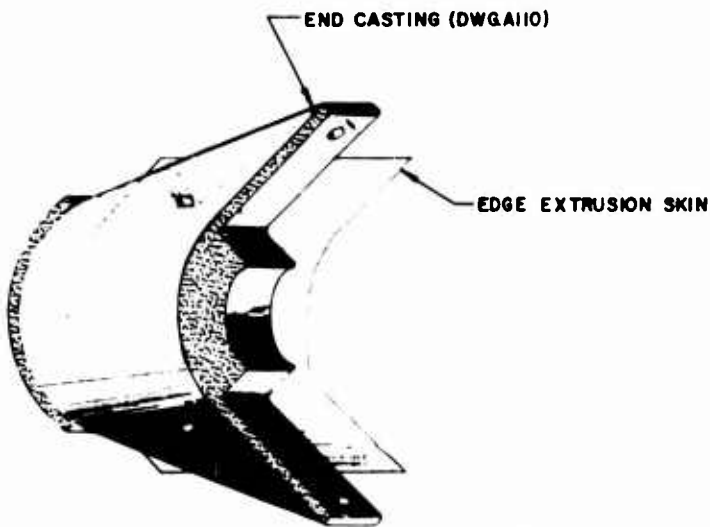


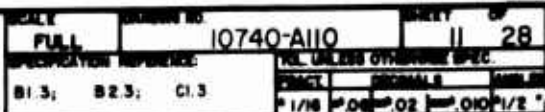
**CLASS I & II
EXTRUSION END CASTING**

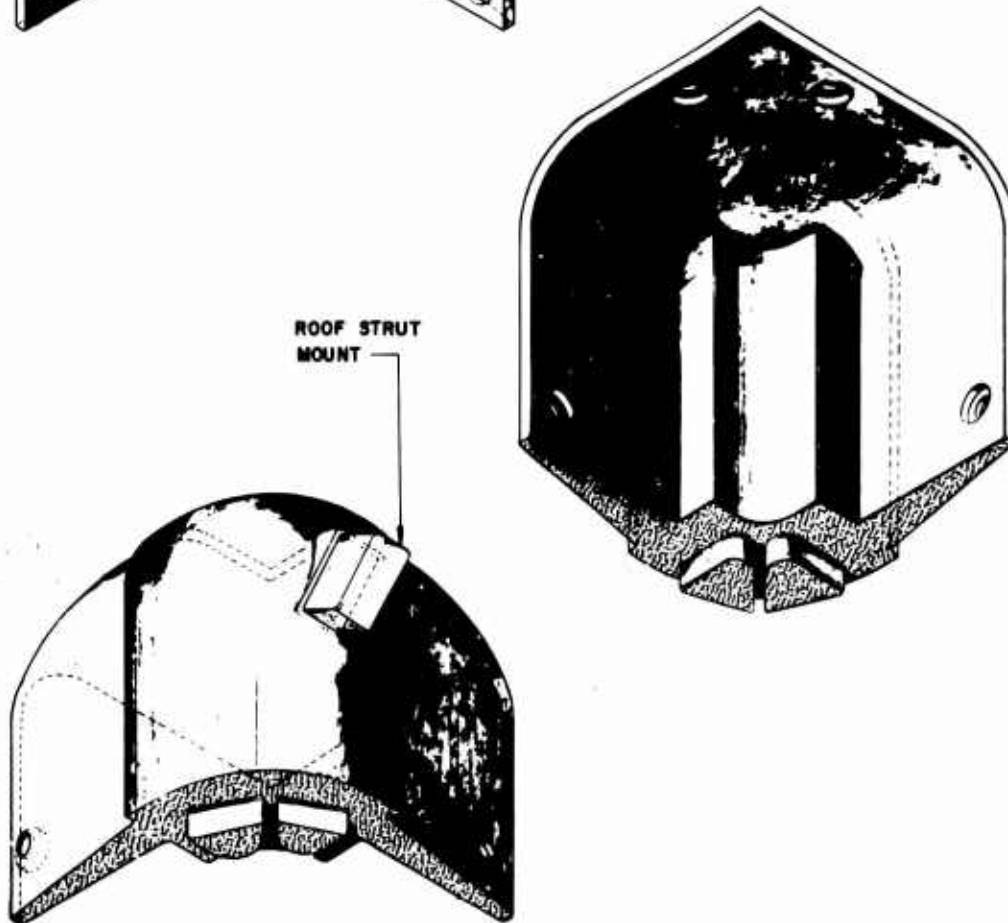
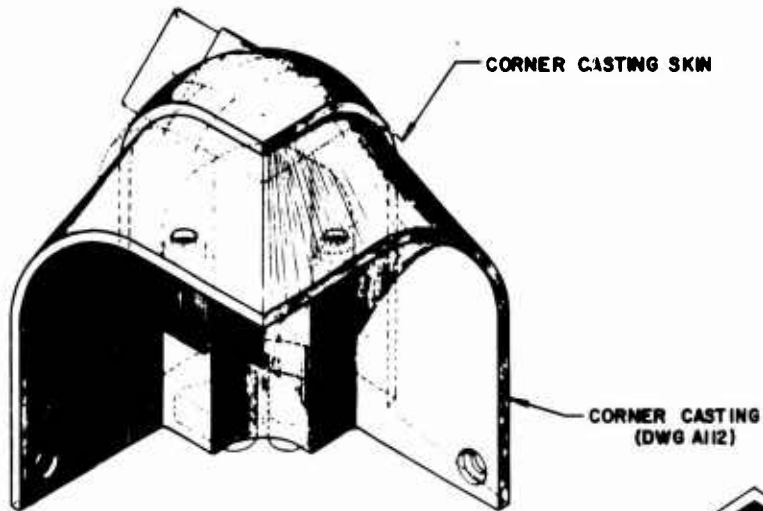
SCALE	1/2	10740-A109	10	28
COMPONENT REFERENCE	B1.3, B2.3, C1.3	1/16	0.02	0.010
FINISH	1/16	0.02	0.010	1/2



END CASTING (DWG A110)



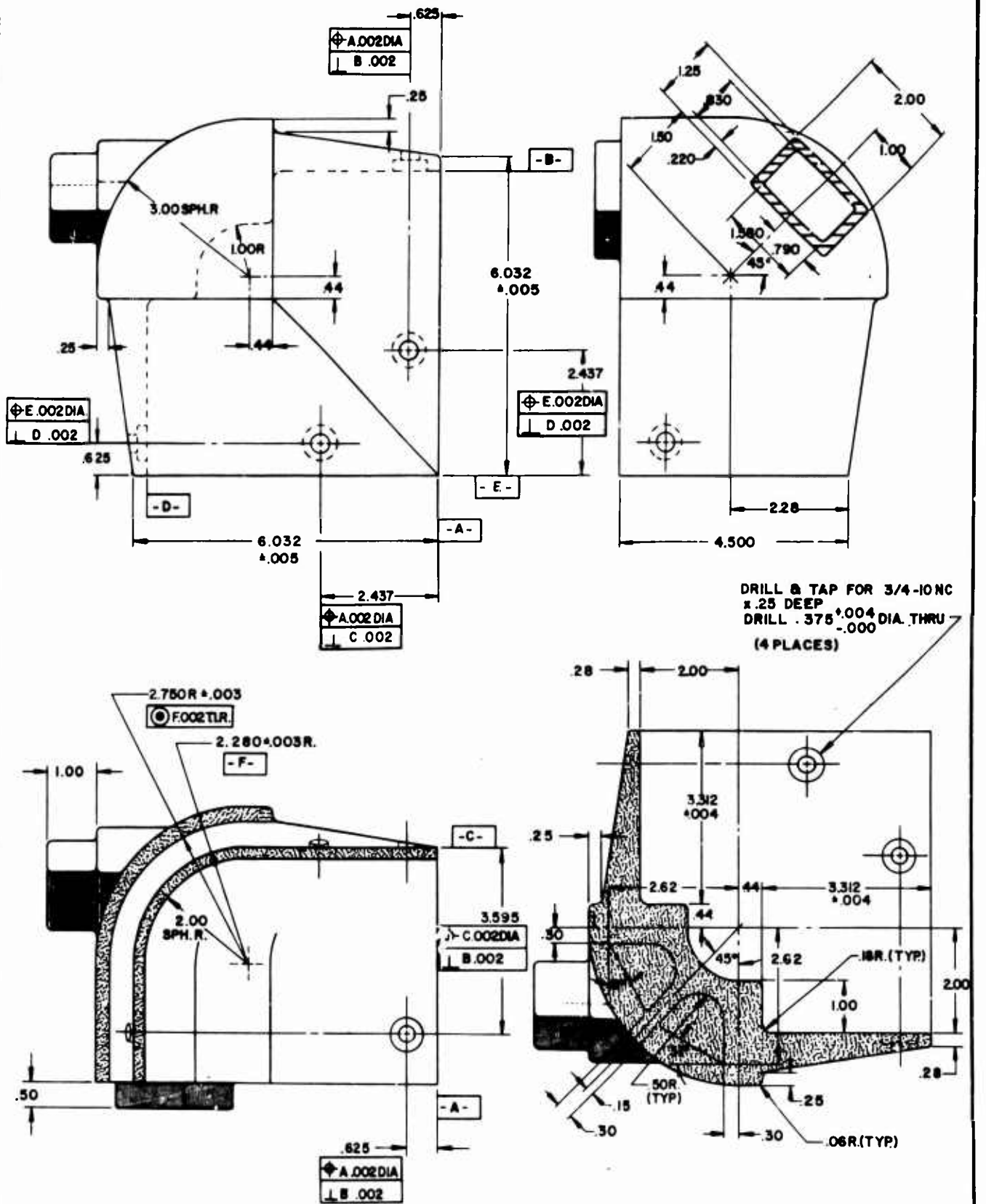






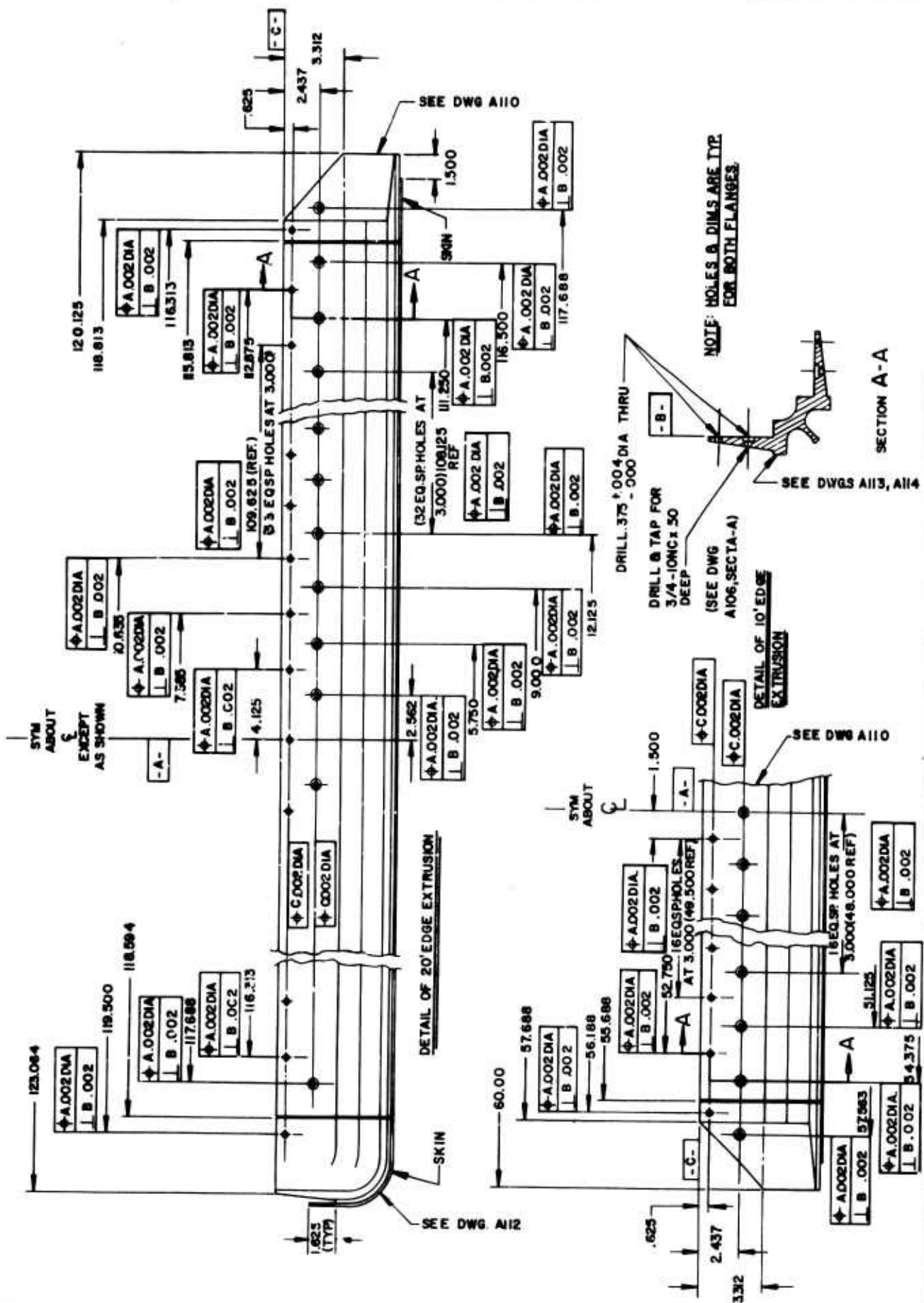
CLASS I & II EXTRUSION END
CORNER CASTING DETAIL

SCALE	3/4	DRAWING NO.	10740-A112	SHEET OF	13 28
SPECIFICATION REFERENCE:	TOL. UNLESS OTHERWISE SPEC.				
F.1.3.	B.2.3.	C.1.3	FRAC.	DECIMAL	INCHES
			1/16	0.0625	0.0156





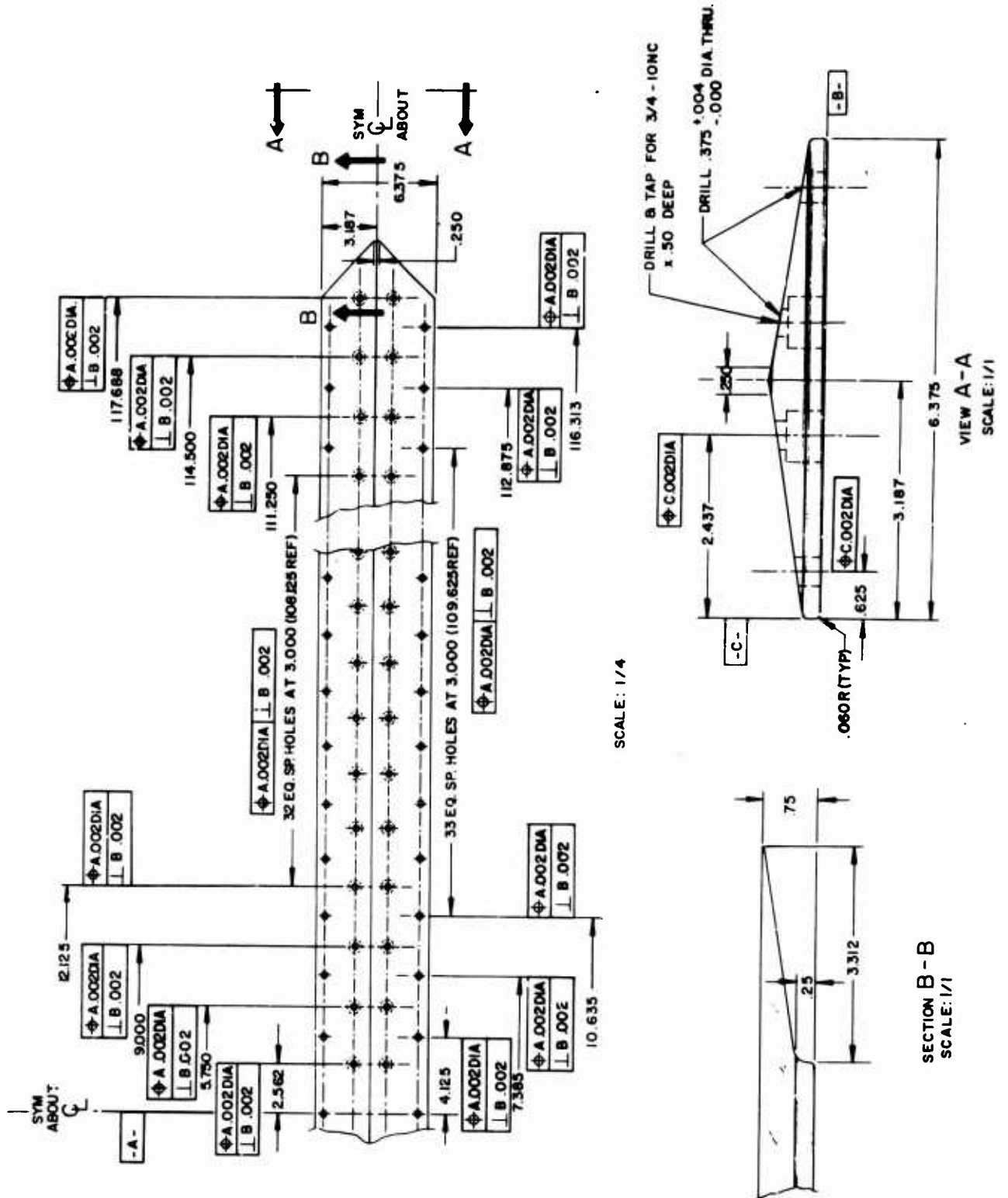
SCALE 1/4	DRAWING NO. 10740-A113	SHEET OF 14 28
SPECIFICATION REFERENCE: B1.2.2, B1.3.2, B2.2.2; B2.3.2; C1.2, C2.2		TOL. UNLESS OTHERWISE SPEC. FRACTION DECIMALS MILLIMETERS 1/16 .0625 .001 1/8 .125 .002





CLASS I & II
CENTER EXTRUSION DETAIL

SCALE NOTED	DRAWING NO 10740-A114	SHEET OF 15 28
SPECIFICATION REFERENCE: B1.2.2, B1.3.2, B2.2.2, B2.3.2, C1.2, C2.2		
TOL. UNLESS OTHERWISE SPEC.		
FRAC.	DECIMALS	INCHES
1/16	.005	.010
1/32	.002	1/8"

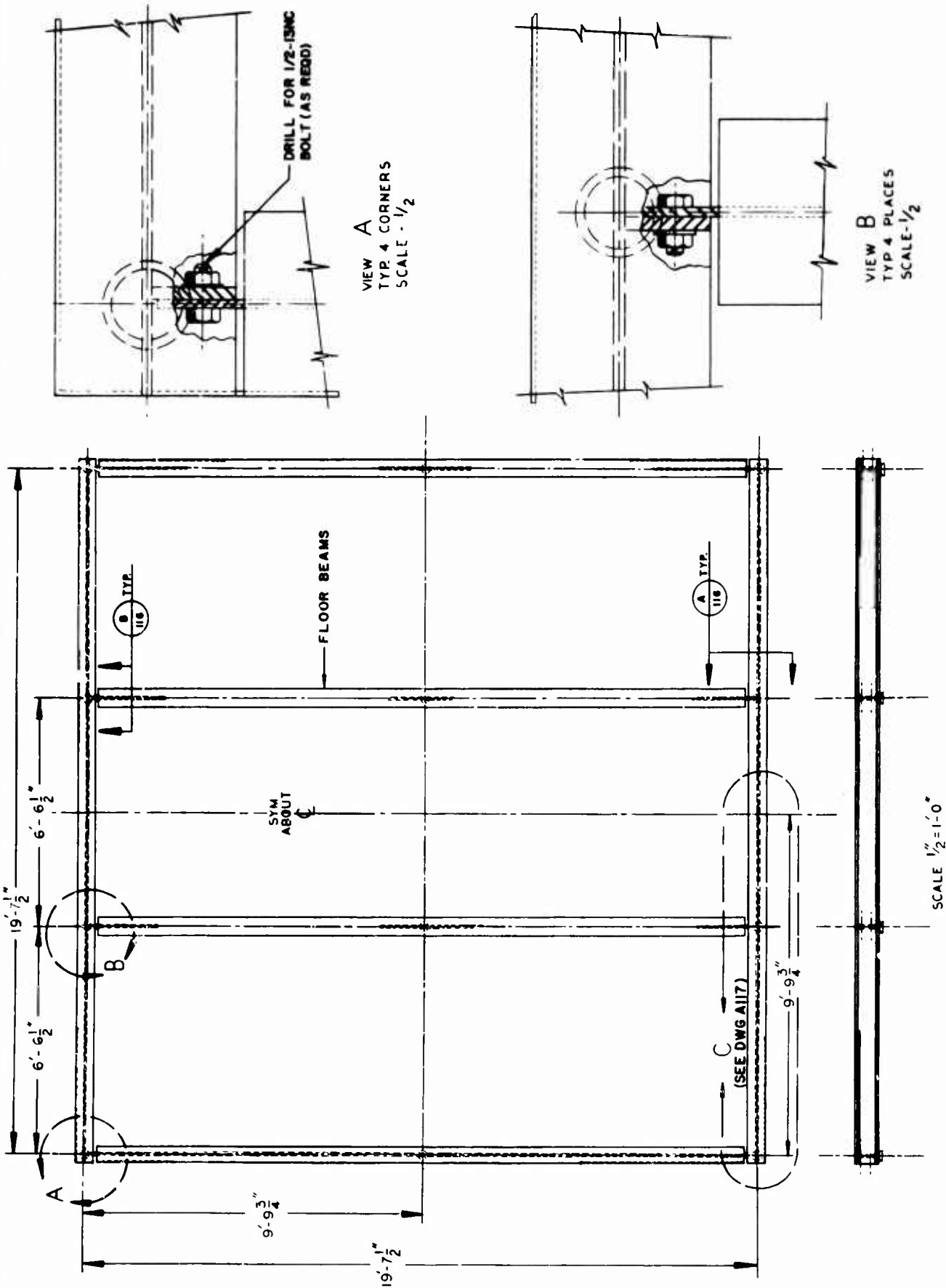




GENISCO
TECHNOLOGY
CORPORATION

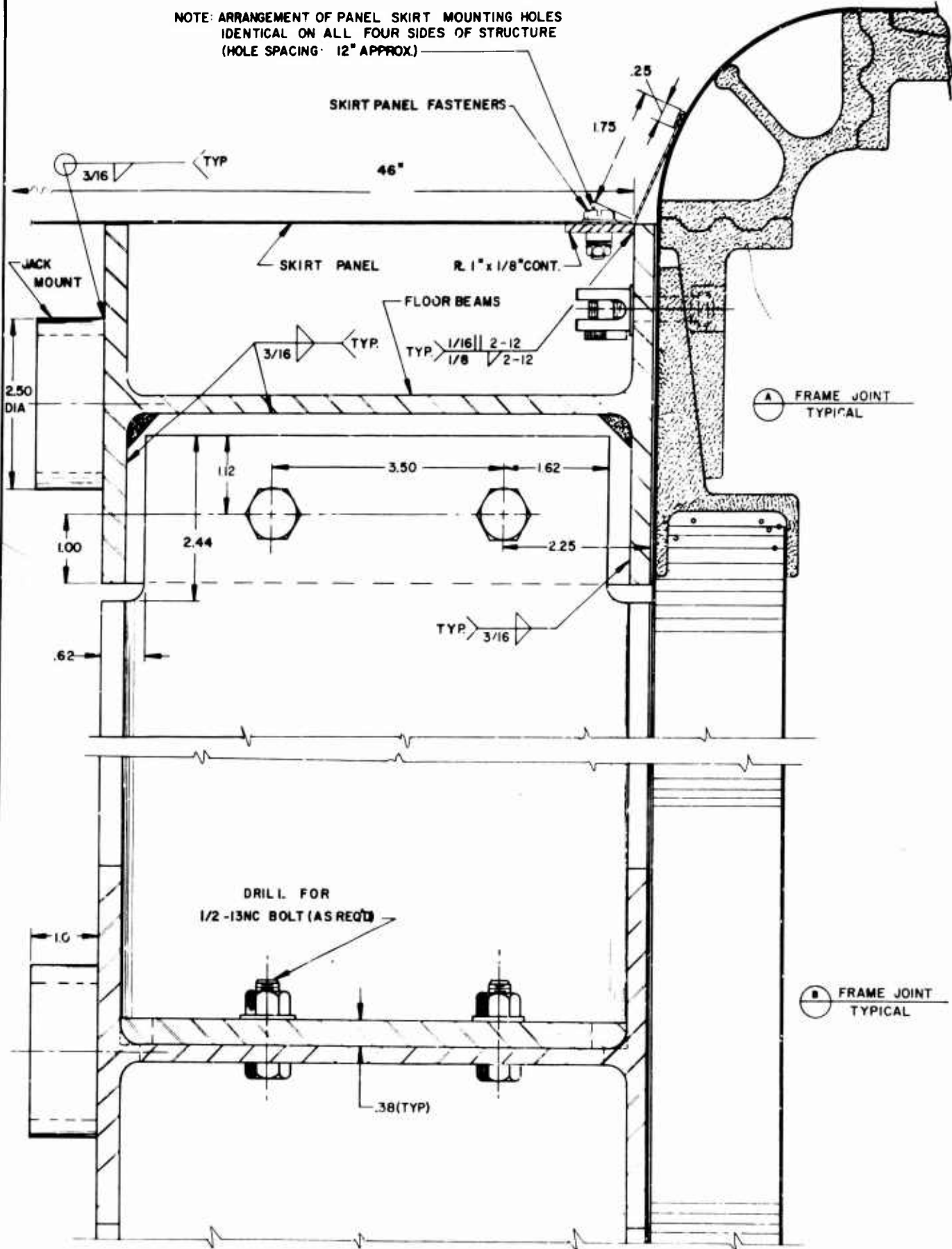
CLASS I & II
RAISED SUPPORT FRAME

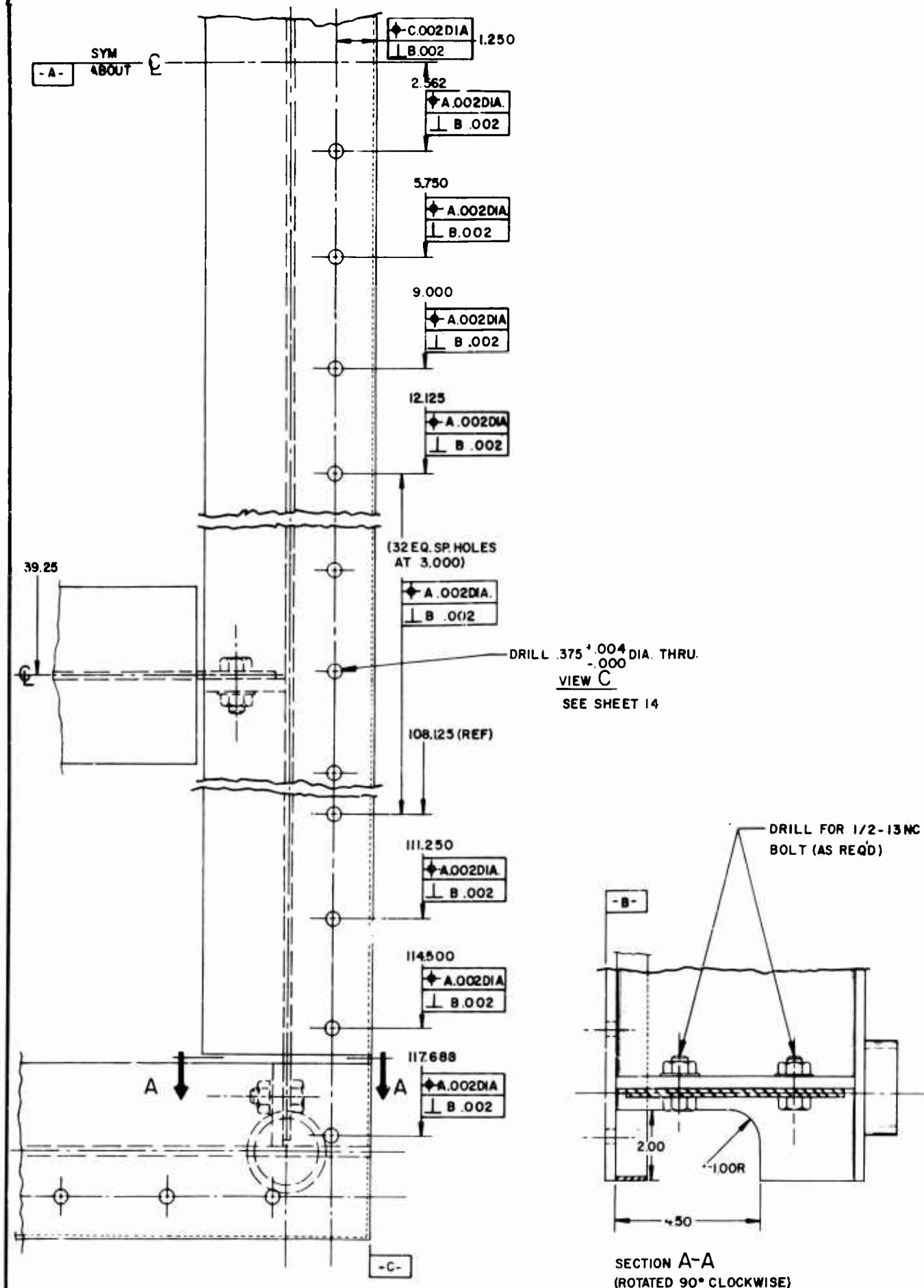
SCALE	NOTED	DRAWING NO.	10740-A115	REV	16 28
SPECIFICATION REFERENCE:	TOL. UNLESS OTHERWISE SPEC.				
B1.5, B2.5, C1.5	FRACT.	NORMAL	FINISH		
	1/16	0.0002	0.010	1/2"	

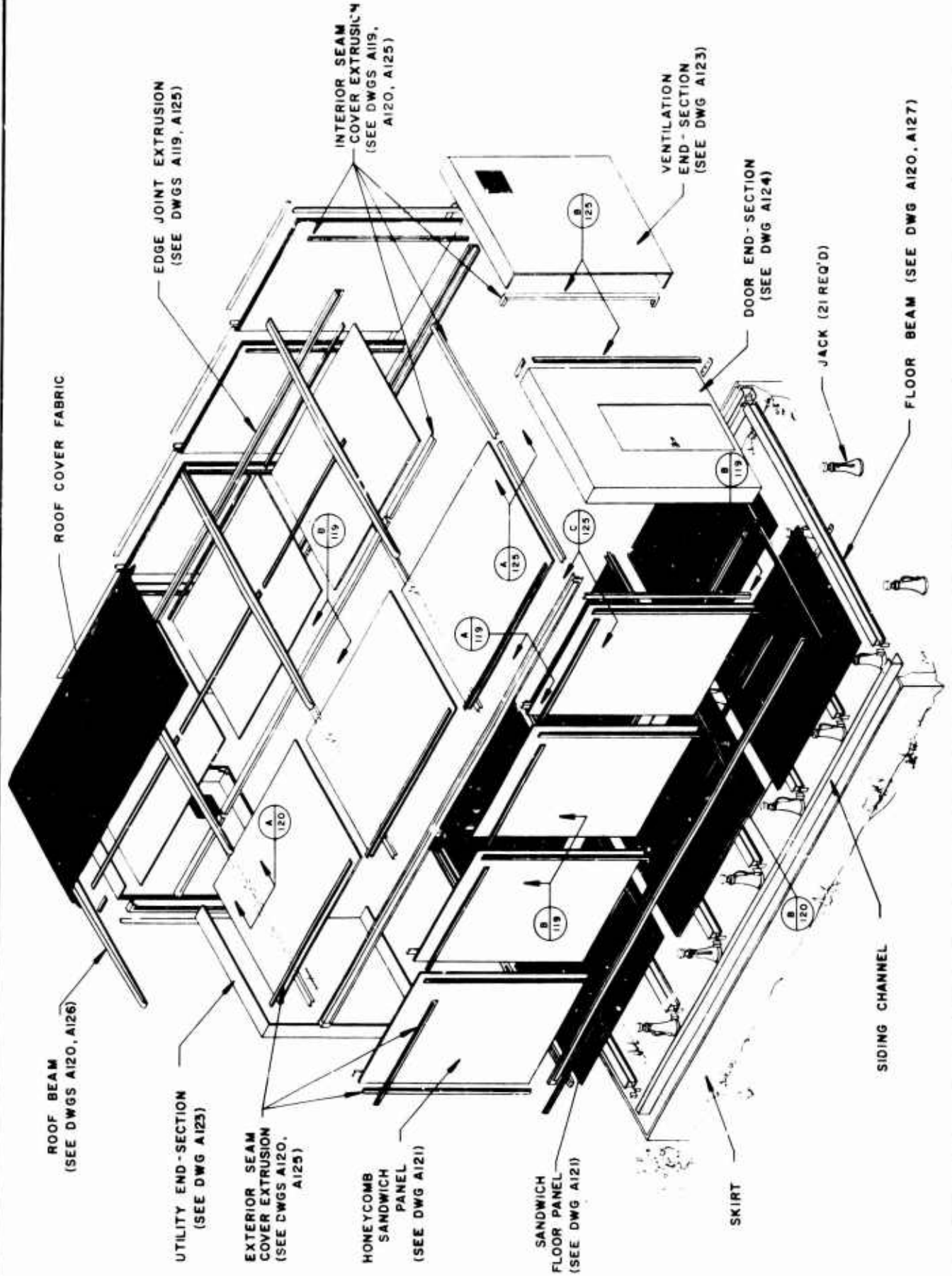


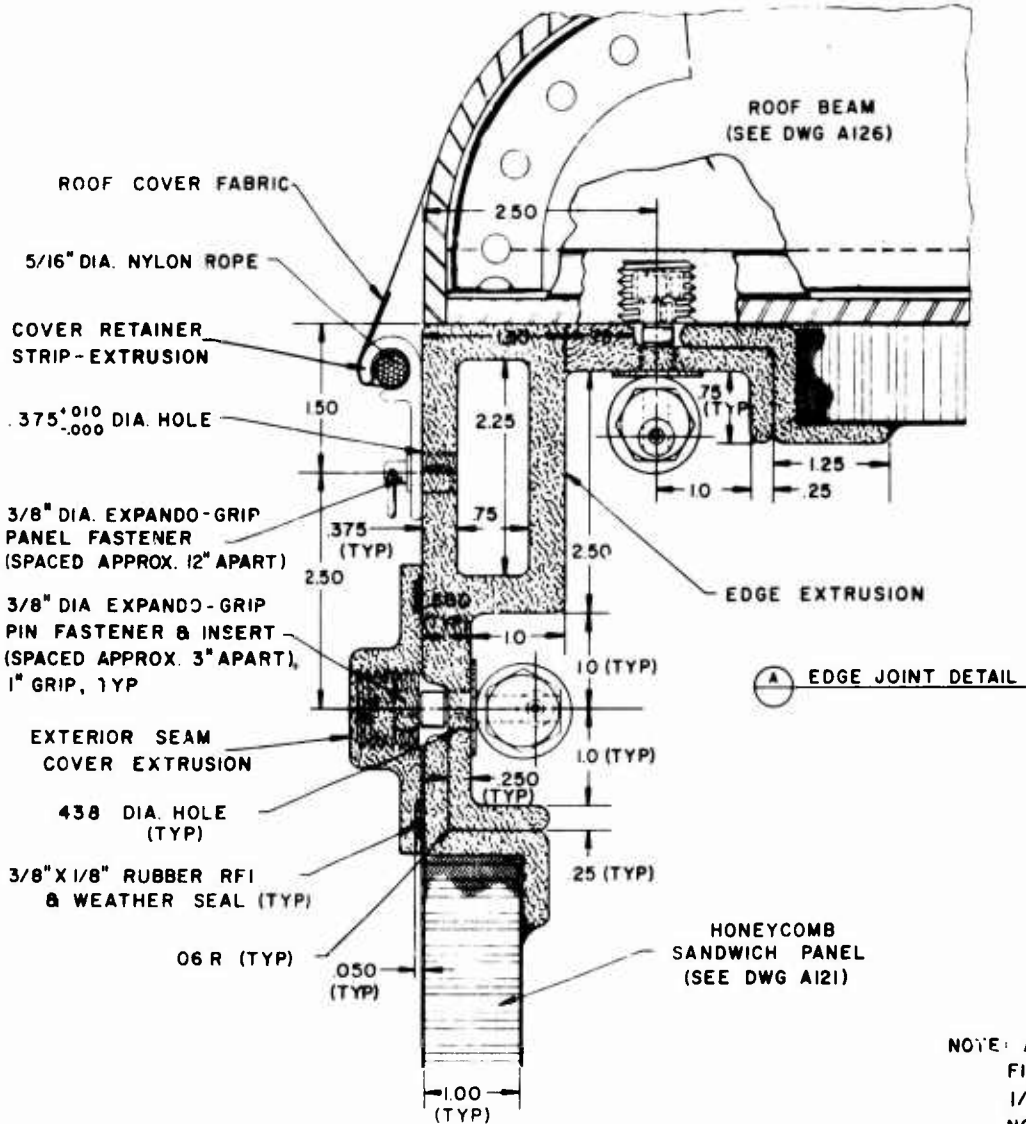
RAISED SUPPORT FRAME JOINT
DETAIL - CLASS I & II

NOTE: ARRANGEMENT OF PANEL SKIRT MOUNTING HOLES
IDENTICAL ON ALL FOUR SIDES OF STRUCTURE
(HOLE SPACING 12" APPROX.)

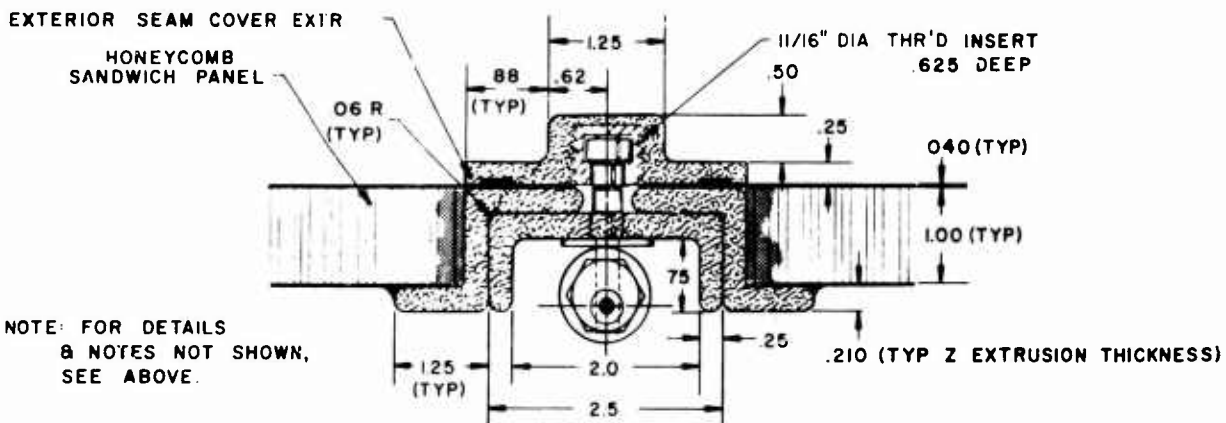








NOTE: ALL EXTRUDED
FILLETS & ROUNDS
1/8" R EXCEPT AS
NOTED.



NOTE: FOR DETAILS
& NOTES NOT SHOWN,
SEE ABOVE.

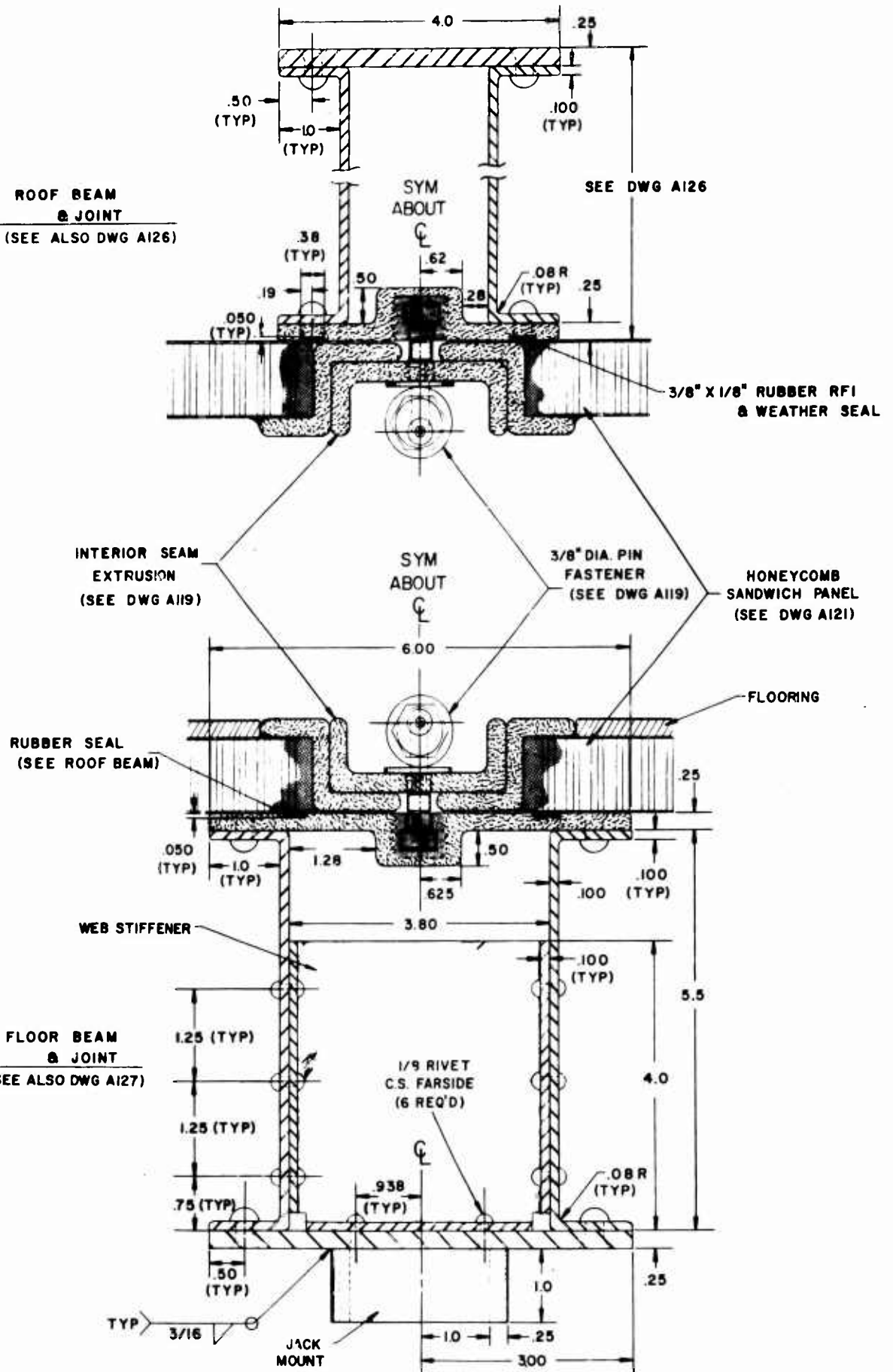
Ⓑ BASIC PANEL JOINT DETAIL



CLASS III ROOF & FLOOR BEAM
CROSS-SECTION & JOINT DETAIL

SCALE	DRAWING NO.	SHEET OF
FULL	10740-A120	21 28
SPECIFICATION REFERENCE:	VOL. 10.100 OFFSHORE SPEC.	
B3.2; B3.3; B3.7; C3.3	FACT	DETAILS
	1/16	1/8

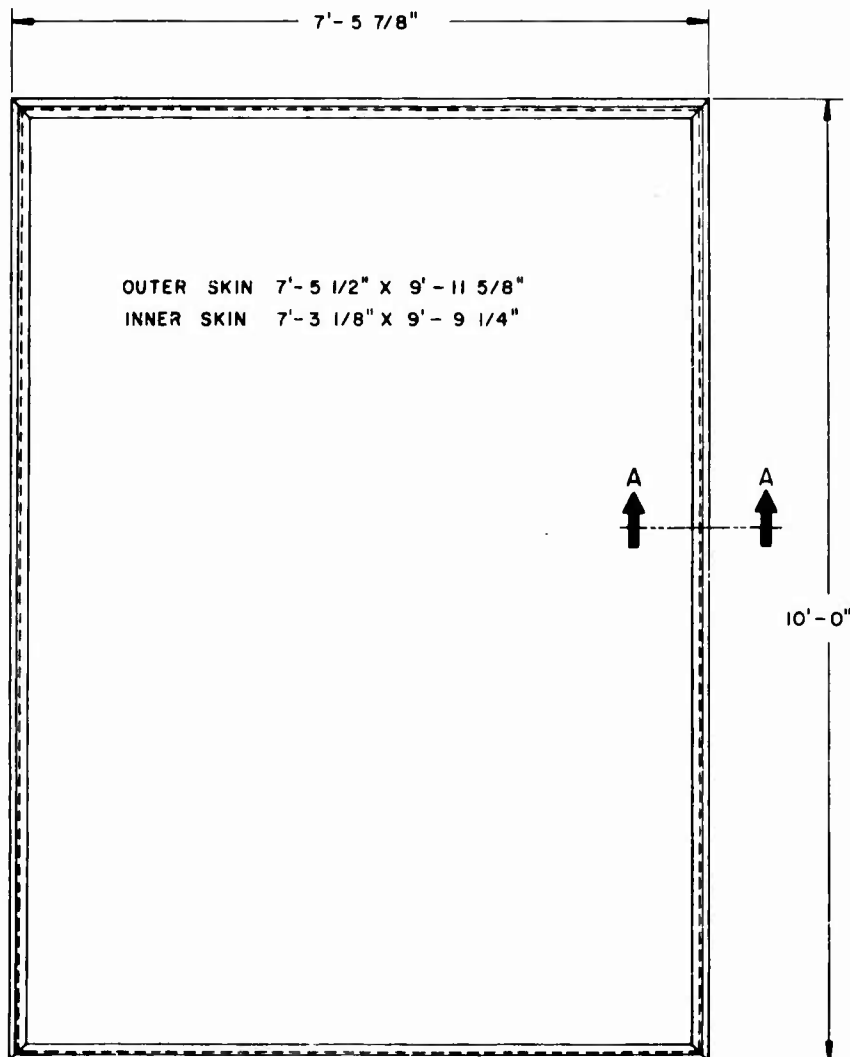
ROOF BEAM
& JOINT
(SEE ALSO DWG A126)



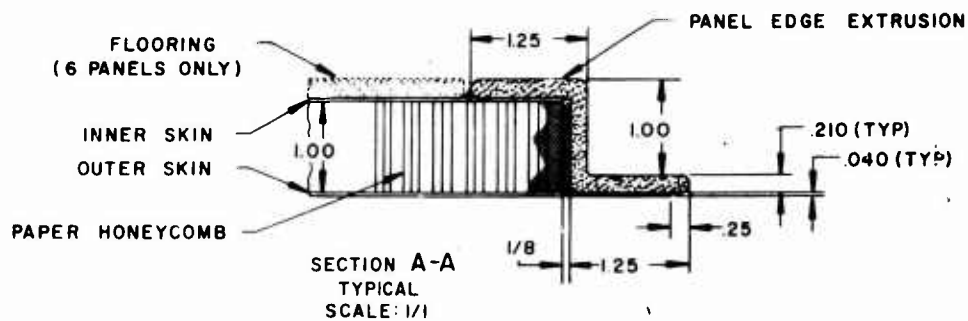


HONEYCOMB SANDWICH
PANEL DETAIL - CLASS III

SCALE	DRAWING NO	SHEET OF
NOTED	10740-A121	22 28
SPECIFICATION REFERENCE:		
B31, B32, B37, C31, C32, C37		
FRMT	DECIMALS	INCHES
1/16	0.00 0.02 0.010	1/8



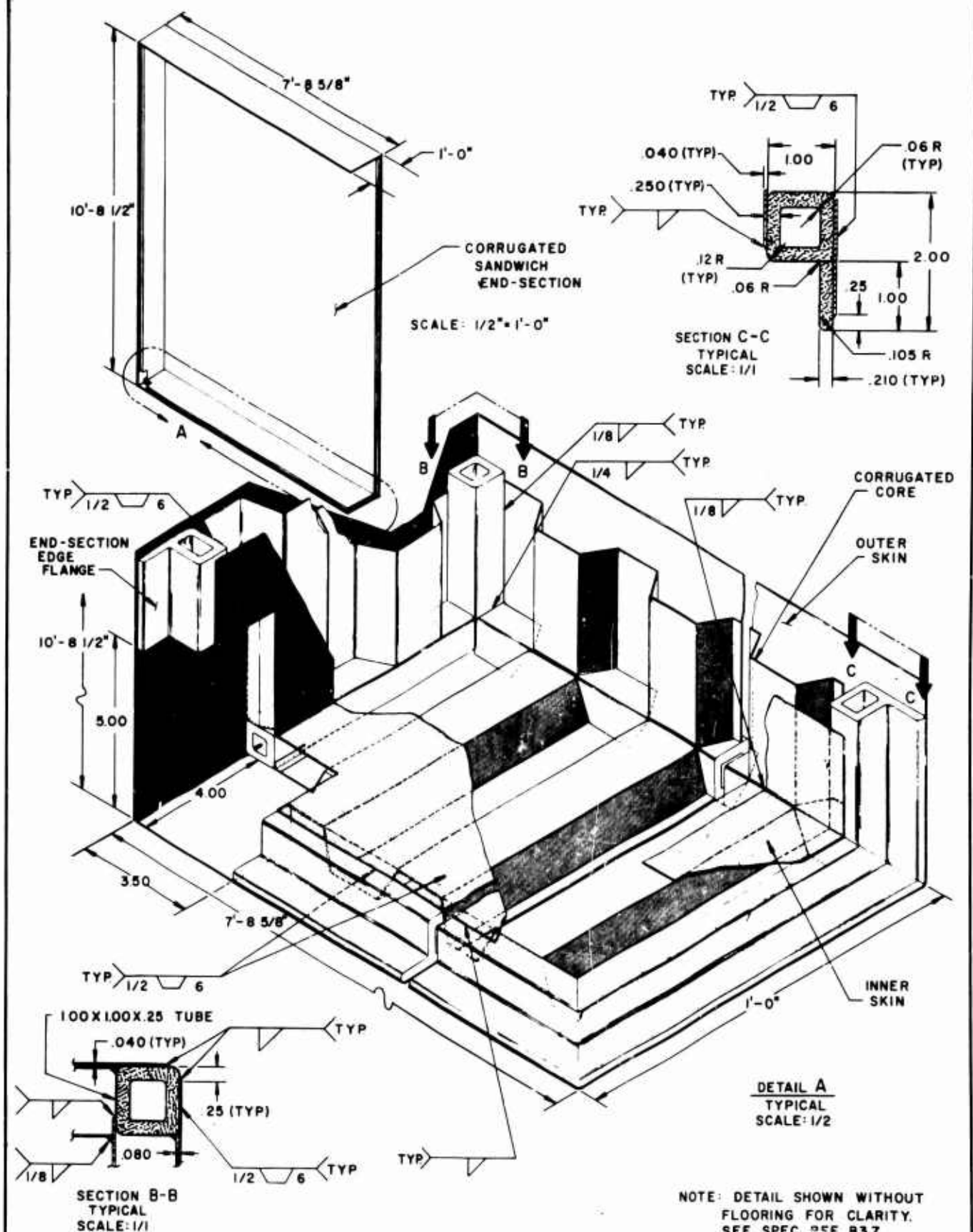
SCALE: 1" = 1'-0"

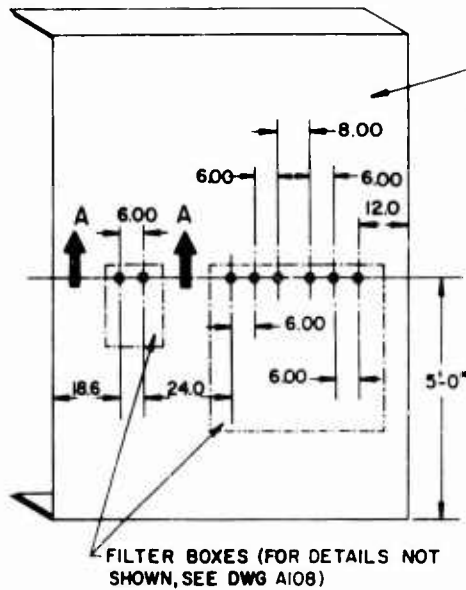




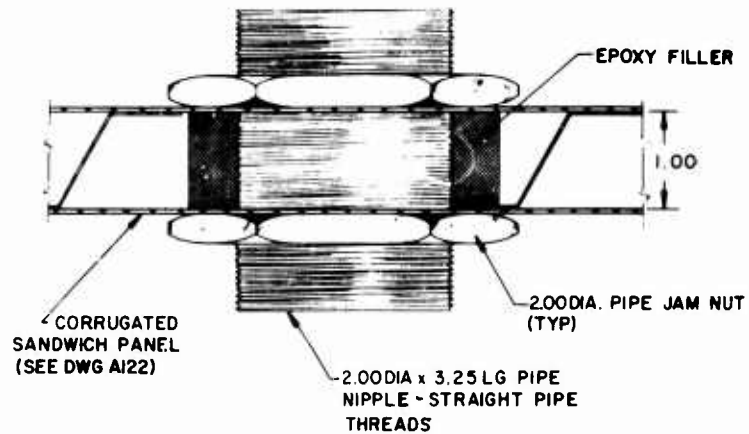
BASIC END-SECTION DETAIL-CLASS III

SCALE	DRAWING NO.	SHEET OF
NOTED	10740-A122	23 28
SPECIFICATION REFERENCE:		
B3.2, B3.5, B3.7, C3.2, C3.5		
POL. UNLESS OTHERWISE SPEC.		
DATE	REVISION	APPROVED
1/18	0.06	0.02
	0.010	1/8"

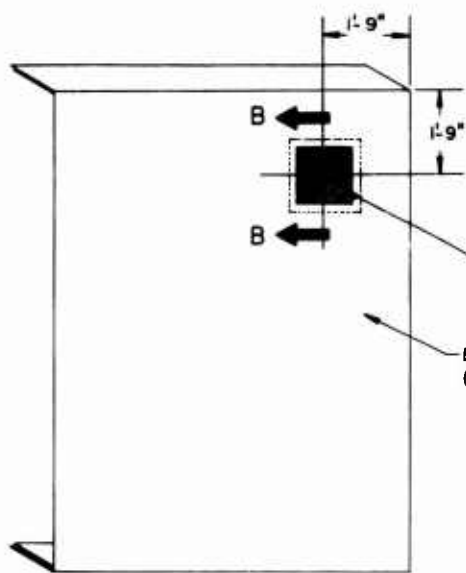




UTILITY END-SECTION
BASIC END-SECT.
(SEE DWG. A122)

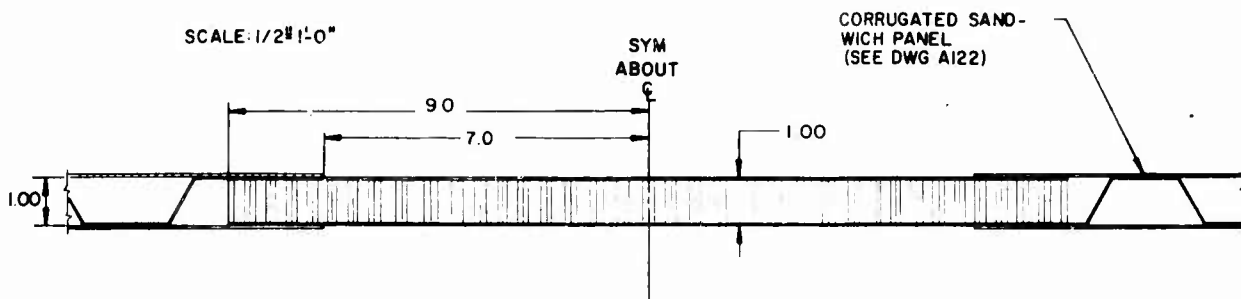


SECTION A-A
TYPICAL
SCALE: 1/1

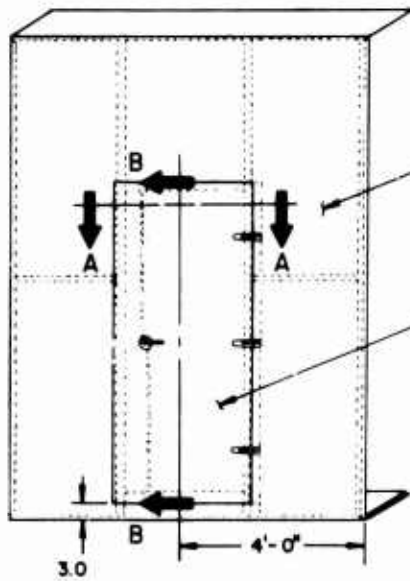


VENTILATION END-SECTION
BASIC END-SECTION
(SEE DWG A122)

SCALE: 1/2"=1'-0"



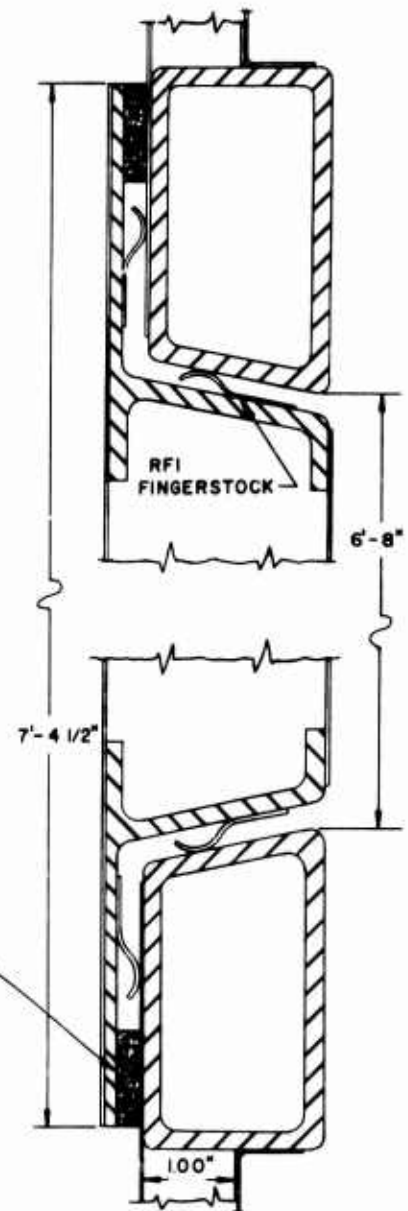
SECTION B-B
SCALE: 1/2



DOOR END-SECTION
SCALE: 1/2"=1'-0"

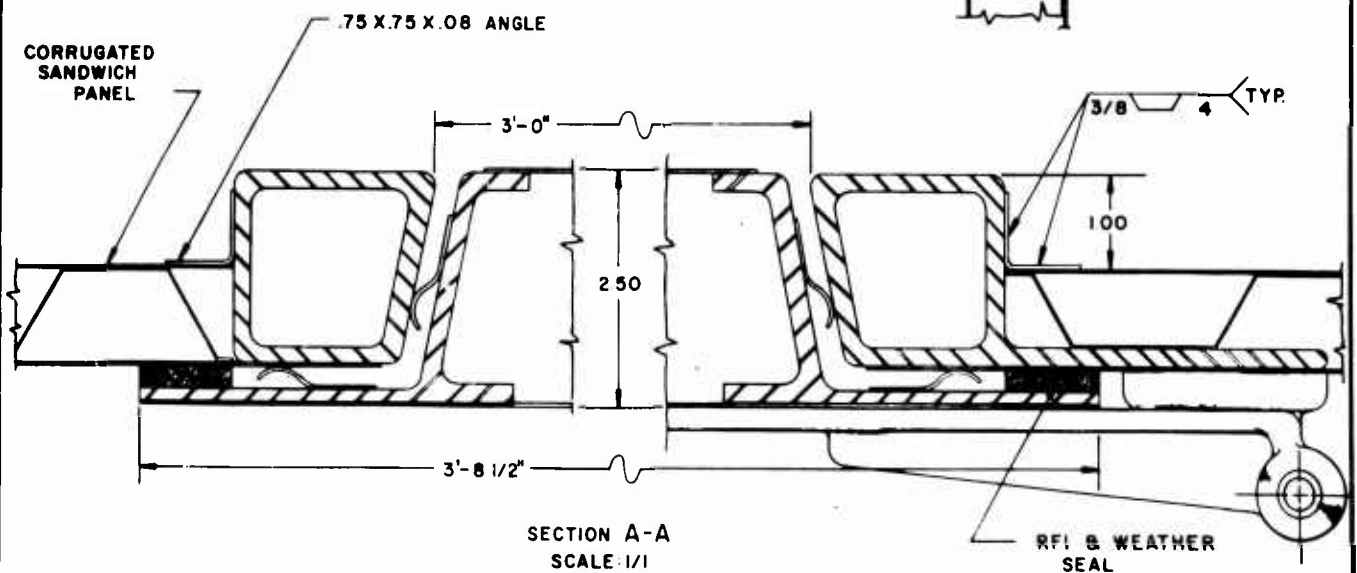
BASIC END-SECTION
(SEE DWG A122)

TYPICAL FILTRON
DOOR ASSEMBLY



RFI & WEATHER
SEAL

SECTION B-B
SCALE: 1/1



SECTION A-A
SCALE: 1/1

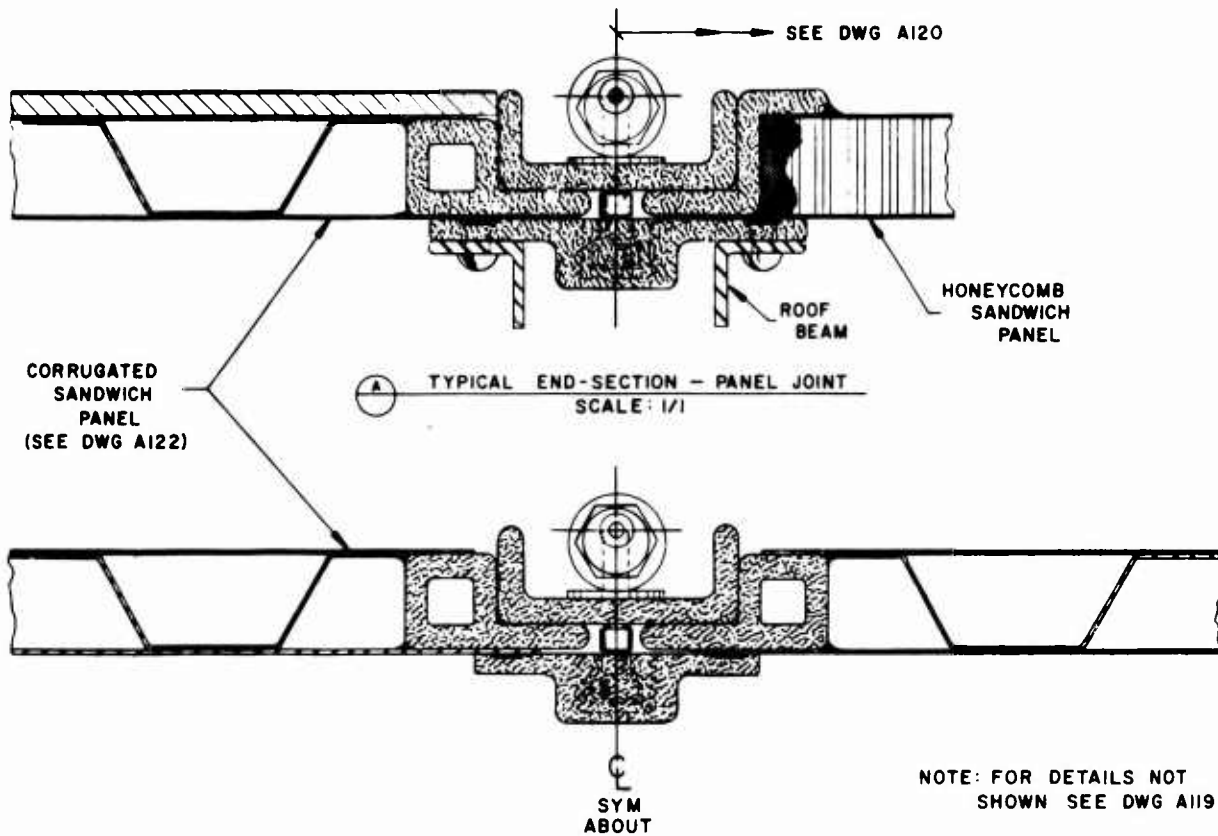
RFI & WEATHER
SEAL



GENISCO
TECHNOLOGY
CORPORATION

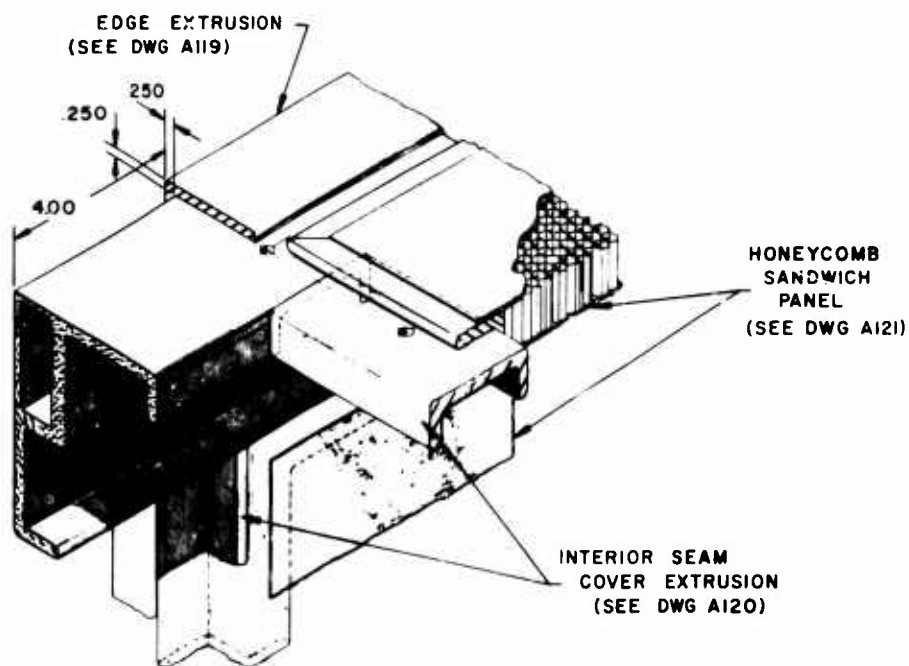
CLASS III END-SECTION JOINT DETAIL

SCALE	NOTED	10740-A125	SHEET OF	26 28
SPECIFICATION REFERENCE:		VOL. UNLESS OTHERWISE SPEC.		
B3.2; B3.5; C3.2; C3.5		FIGURE	REVISION	DATE
		1/18	1/18	1/18

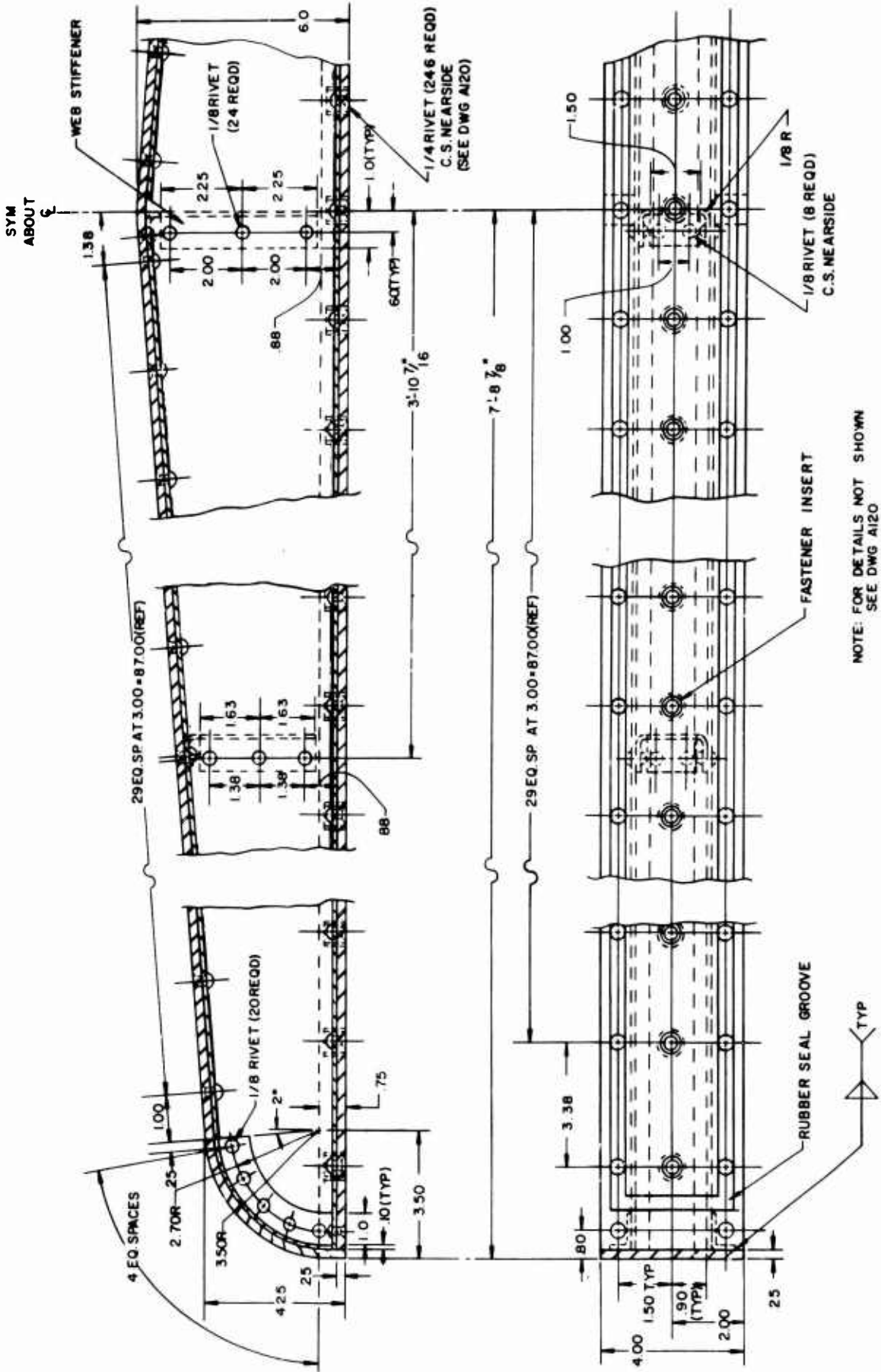


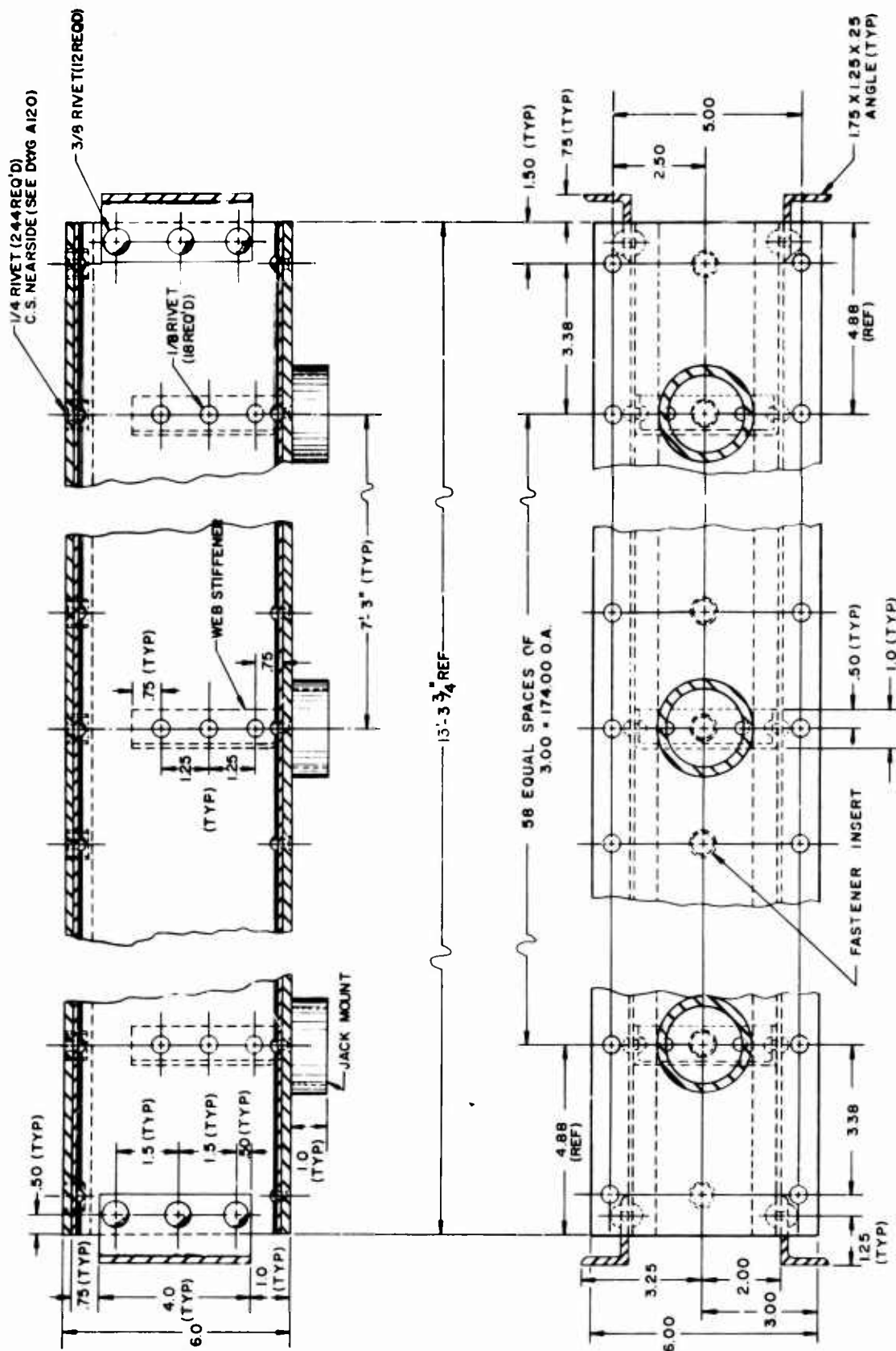
NOTE: FOR DETAILS NOT SHOWN SEE DWG A119.

⑧ TYPICAL END-SECTION JOINT
SCALE: 1/1



⑨ EDGE EXTRUSION END-SECTION
SCALE: 1/2





NOTE: FOR DETAILS NOT SHOWN,
SEE DWG A120.

APPENDIX III

SECTION B

SPECIFICATION REFERENCES MATERIALS AND FABRICATION NOTES

Presented below are the required materials and notes for the fabrication of the three classes of shielded enclosures. The materials for each class of enclosure are divided first into enclosure components and then into basic component materials. Two options for the Class I enclosure are given. Each option is presented separately and references are given for the appropriate drawings. In the title block of each drawing will be found a Specification Reference space. This space will be used to refer to the following section numbers as they apply to a given drawing.

1.0 CLASS I SHIELDED ENCLOSURE - STEEL OPTION

This option for the Class I Enclosure conforms to the existing drawings with no modifications.

CLASS I SHIELDED ENCLOSURE - ALUMINUM OPTION

This option for the Class I Enclosure conforms to the Class II Enclosure design and drawings with one modification. For Class I, the honeycomb sandwich panel skins are 16 gage (.050) 6061-T6 aluminum. The specifications for the remaining items will be found in Paragraph 2.0.

1.1 HONEYCOMB SANDWICH PANEL

1.1.1 Material Specifications

Skin: 24 gage (.028) galvanized steel conforming to ASTM-A-446-64T, Grade C(1.156 lbs/ft²).

Core: 2" Kraft paper honeycomb conforming to MIL-H-21040, Type I, Class I at .22 BTU/ft²/ F.

Adhesives: Resin adhesive per FED-STD-MMM-A-132, Type I, Class 3.

Door Assembly: See Section 1.6.

Air Vents: See Section 1.7.

Panel Edge Extrusion: See Section 1.2.

1.1.2 Fabrication Notes

Skin Preparation: Special attention should be given to the preparation of the galvanized surfaces for bonding to the paper honeycomb. In order to produce adequate bond, this may require roughing the bonding surface of the skin or even stripping the galvanize on the one side prior to bonding. These surfaces should be thoroughly cleaned in any case.

Panel Edge Attachment: The method of attachment for the panel edge extrusion shown in the drawings is only one of several tentative approaches. With this approach an inner structural bonding adhesive and exterior RF shielding (non-structural) epoxy may be used to bond the paper honeycomb to the skin. An RF shielding epoxy similar to the Eccobond Solder (manufactured by Emerson and Cuming, Inc.) or equivalent is recommended.

Resistance welding or riveting could also be employed for this attachment. However, special attention should be given to the possible effects of warping which could render this approach infeasible. Blind type rivets would be necessary in order to prevent potential seam leakage. The panel edge extrusion would be changed to accommodate this concept. Rivet spacing should be held between one and two inches apart. A thin coating of RF shielding epoxy may be required between the skins in order to maintain the shielding integrity.

Alternate configurations for the panel edge extrusion to skin attachment may become feasible as a result of

improved techniques and future developments in the manufacture of sandwich panels.

Lifting Eyes: Lifting eyes are required during assembly of the enclosure and must be removed during shipping and after erection. Thus, blind tapped holes are recommended at each corner of the panels. This should be considered at the time of manufacture.

1.2 EXTRUSIONS (includes all extruded components)

1.2.1 Material Specifications

Grade 4330 MIL-S-8699 or equivalent
Camber - not greater than 1/8" in any five (5) feet
Twist - not greater than .188 in any five (5) feet
Flatness (flanges only) - .020
Condition - extruded and straightened
Finish - pickled, descaled, blast cleaned and electro-galvanized per ASTM-A-164, Type GS

1.2.2 Fabrication Notes

Edge Joint Extrusion: Due to the large cross-section and circumscribed diameter for this item, it becomes necessary to extrude three component parts and fabricate the edge joint extrusion (see A103). See Section 1.1.2 for a discussion of applicable joining techniques.

Extrusion - Casting Joint: Particular attention should be given to the extrusion to casting joint. Methods of joining include welding and epoxy. Welding may produce warping and should be given careful consideration prior to attempting this technique. Epoxy would appear the most feasible to apply, however, RF integrity may be difficult to maintain. It should be further noted, that alignment of these end castings is critical and extreme care should be taken during this effort.

Edge Extrusion Skin: After the edge extrusion and end castings have been fabricated to form a complete edge piece (see Drawing A113), a skin covering is

attached as shown in the cross-section on Drawing A103. This skin extends over the casting-extrusion joint as can be seen from the dotted skin lines in Drawings A109 and A111. See Section 1.1.2 for suggested attachment techniques.

Hole Placement: See Section 1.1.2.

1.3 CASTINGS

1.3.1 Material Specifications

Low alloy steel conforming to ASTM-A-487 (minimum yield 50 KSI)
Finish - electrogalvanized per ASTM-A-164, Type GS

1.3.2 Fabrication Notes

Extrusion-Casting Joint: See Section 1.2.2.

Casting Skin: The skin shown covering the end and corner castings in the isometric Drawings A109 and A111 is the same skin shown in Drawing A103 as the edge extrusion skin. See Section 1.2.2.

Tolerance: If tolerances cannot be maintained sufficiently for RF shielding with the existing metal to metal contact design, an alternate approach will become necessary. A possible alternate would be to coat the contact surfaces of these castings with a conductive RF shielding silicon rubber.

1.4 WEATHER PROTECTION ROOF

1.4.1 Material Specifications

Frame: 4" x 4" x 3/16" tubing, 2" x 1 1/4" x 1/8" tubing and preformed 1/4" cap plate of structural steel conforming to ASTM-A-441 for welded roof frame per Drawings A101 and A102.

Cover Fabric: Vinyl Coated Nylon, Can-Spec-PVC 22 (22 oz/sq yd) conforming to MIL-C-43086.

Cover Retainer Extrusion: See Section 1.2.1.

Roof Frame Stay: USS Tiger Brand 1 x 19 zinc coated 3/8" steel wire rope with USS drop-forged galvanized steel 3/8" wire rope sockets and Bethlehem Steel jaw and jaw drop-forged galvanized steel turbuckle with pins or equivalent. An alternate could be Bethlehem Purple Strand 7/16" galvanized steel wire rope and associated hardware. The required tension capability (breaking strength) is 15 kips.

1.4.2 Fabrication Notes

Fabric Retainer Straps: Tie down straps on the cover fabric (not shown) should be provided in order to secure the cover to the frame. All edges are secured by means of a rope sewn into the hem of the cover, which slips into the cover retainer extrusion and is tied at the corners.

1.5 RAISED SUPPORT FRAME

1.5.1 Material Specifications

Beams: 8WF17 ASTM-A-36 or 6B8.5 ASTM-A-441 (desirable).

Skirts: 22 gage (.034) galvanized steel per ASTM-A-446 and ASTM-A-245, Class A.

Jacks: Minimum of 10 ton capacity with an average height for jack and base support (if required) of 24 inches. (i.e. Simplex Ball-Bearing Screw Jack, Blackhawk Hydraulic Jack, etc.)

Fasteners: Skirt Panel Fastener - 3/8" Expando Grip Panel Fastener Part Number EGK 6 P SIS. Beam Bolts - 1/2 - 13 NC structural bolts conforming to Specification ASTM-A-325.

1.5.2 Fabrication Notes

Beam Preparation: The cross beams should be coped as shown in Drawing A116 in order to properly mate with the edge beams. All edge beams should have a thin coating of silicon rubber applied to the outside surface of the upper flange for weather protection after hole drilling. (See Drawings A116 and A117). It is desirable if this coating could also have RF shielding properties.

1.6 RF SHIELDING DOOR ASSEMBLY

The door shown is a typical RF shielding double steel door commercially available from Filtron Company, Inc. Alternate door assemblies are also commercially available, and could be used, however, modification may be necessary in order to incorporate the various door jams into the sandwich panel. The required opening is 6' - 8" x 6'.

1.7 RF SHIELDING AIR VENTS

1.7.1 Material Specifications

Tecknit EMC Teckcell 60 43 16 x 16 03 04 or equivalent.

1.7.3 Fabrication Notes

Two approaches to installation of these vents have been considered; first, to install the vents permanently in the honeycomb sandwich panel (shown in Drawing A108) and second, to install replaceable vents in the completed sandwich panel (specified above). Either approach should be adequate for RF shielding.

1.8 FLOORING

The flooring shown in Drawing A105 is 3/4" plywood. Other materials are commercially available which are

much lighter, however, plywood is the least costly. The primary function of the flooring is to prevent puncture of the inner skin of the honeycomb sandwich panel under concentrated loads. Any material which will provide puncture resistance to the skin such as floor tile, epoxy coatings, etc. should be adequate.

1.9 PANEL FASTENERS

The panel fastener shown in Drawing A103 is a modified 3/8" diameter Expando-Grip Pin Fastener, similar to an EGP 6 E 12KRT Pin Fastener, (yielding approximately 3800 lbs clamp up pressure) available from Adjustable Bushing Corporation, North Hollywood, California. In the modified version, this fastener is stainless steel and has a specially designed thrust washer (shown in Detail A, Drawing A103). The cam handle is removed and a hex head is cast into the cam for use with any hex socket wrench for operation. The cam locks in the installed position and can be released by actuating a safety button prior to removal. The last bushing is an Expando-Lock Ring which expands to a larger diameter (as shown in Detail A, Drawing A104) yielding greater tensile load capability.

1.10 EXTERNAL OVERLAP STRIPS

1.10.1 Material Specifications

Edge Overlap: 2" x 1/8" galvanized steel strip conforming to ASTM-A-446, Class C.

Center Overlap: 5" x 1/8" galvanized steel strip conforming to ASTM-A-446, Class C.

1.10.2 Fabrication Notes

The external overlap strip is employed primarily for weather protection of the inner seam, thus, the inside surface of all strips should be coated with approximately .040" of silicon rubber. It would be desirable if this coating could also have RF shielding properties.

The fastener hole diameter tolerances are not as critical as those for the flanges, however, care should be taken to locate these holes so that there is no through leakage path for moisture to work into the bushing area of the fastener. However, these strips should not be insulated from the enclosure ground.

1.11 ENCLOSURE ANCHOR AND GROUNDING

All of the vertical external edge overlap strips have 1/2" copper grounding rods securely affixed to them. After assembly of the enclosure these ground rods and overlap strips simultaneously must be implanted and anchored in the terrain and secured to the enclosure (see Drawing A100).

Note: For additional discussion regarding this enclosure, consult Section III of the Final Report for Air Force Contract Number F33615-68-C-1206.

2.0 CLASS II SHIELDED ENCLOSURE - ALUMINUM

This option for the Class II Enclosure conforms to the existing drawings with no modifications.

2.1 HONEYCOMB SANDWICH PANEL

2.1.1 Material Specifications

Skin: 20 gage (.032) 7075-T6 Bare Aluminum conforming to Specification QQ-A-283a Cond. T.

Core: 2" Kraft Paper Honeycomb conforming to MIL-H-21040, Type I, Class 1 @ .22 BTU/ft²/ F.

Adhesives: Resin adhesives per FED-STD-MMM-A-132, Type I, Class 3.

Door Assembly: See Section 2.6.

Air Vents: See Section 2.7.

Panel Edge Extrusion: See Section 2.2.

2.1.2 Fabrication Notes

Skin Preparation: The surface of skins and panel edge extrusions should be deoxidized and then treated with conductive Oakite Chromi-Coat L-25 or equivalent in conformance with MIL-C-5541A prior to fabrication.

Panel Edge Attachment: The method of attachment for the panel edge extrusion shown in the drawings is only one of several tentative approaches. With this approach an inner structural bonding adhesive and exterior RF shielding (non-structural) epoxy may be used to bond the paper honeycomb to the skin. An RF shielding epoxy similar to the Eccobond Solder (manufactured by Emerson and Cuming, Inc.) or equivalent is recommended.

Resistance welding or riveting could also be employed for this attachment. However, special attention should be given to the possible effects of warping which could render this approach unfeasible. Blind type rivets would be necessary in order to prevent potential seam leakage. The panel edge extrusion would be changed to accommodate this concept. Rivet spacing should be held between one and two inches apart. A thin coating of RF shielding epoxy may be required between the skins in order to maintain the shielding integrity.

Alternate configurations for the panel edge extrusion to skin attachment techniques may become feasible as a result of improved materials and future developments in the manufacture of sandwich panels.

Hole Placement: Special attention must be given to the drilling of the fastener holes. Due to the tight tolerances required, care should be taken to maintain uniform and constant temperature in the various extrusions during hole layout and/or drilling. A variation of 1 degree in the temperature from a specified standard of an extrusion would give rise to a .003" error in the end to end hole dimension. In the event that this requirement cannot be met, a compromise may be necessary with regards to the hole location tolerances and fastener design. It should be further noted that the specified tolerances cannot be firmly established until actual test sections have been fabricated and tested.

Lifting Eyes: Lifting eyes are required during assembly of the enclosure and must be removed during shipping and after erection. Thus, blind tapped holes are recommended at each corner of the panels. This should be considered at the time of manufacture.

2.2 EXTRUSIONS (includes all extruded components)

2.2.1 Material Specifications

Alloy ASA 7075-T6 Aluminum
Straightness (camber) - not greater than 1/16" in any five (5) feet of length, not to exceed 1/2" overall.
Twist - not greater than 1 degree in any four (4) feet of length, not to exceed 3 degrees overall.

Flatness (flanges only) - .013" (.004"/in of width).
Surface - better than 50 RMS
Condition - extruded and straightened
Finish - cleaned, deoxidized and Oakite (conductive ChromiCoat L-25) treated per MIL-C-5541A or equivalent.

2.2.2

Fabrication Notes

Extrusion - Casting Joint: Particular attention should be given to the extrusion to casting joint. Methods of joining include resistance welding and epoxy. Welding may produce warping and should be given careful consideration prior to attempting this technique. Epoxy would appear the most feasible to apply, however, RF integrity may be difficult to maintain. It should be further noted, that alignment of these end castings is critical and extreme care should be taken during this effort.

Edge Extrusion Skin: After the edge extrusion and end castings have been fabricated to form a complete edge piece (see Drawing A113), a skin covering is attached as shown in the cross-section on Drawing A104. This skin extends over the casting - extrusion joint as can be seen from the dotted skin lines in Drawings A109 and A111. See Section 2.1.2 for suggested attachment techniques.

Hole Placement: Special attention must be given to the drilling of the fastener holes. Due to the tight tolerances required, care should be taken to maintain uniform and constant temperature in the various extrusions during hole layout and/or drilling. A variation of 1 degree from a specified standard in the temperature of a 20 foot extrusion would give rise to a .003" error in the end to end hole dimension. In the event that this requirement cannot be met, a compromise may be necessary with regards to the hole location tolerances and fastener design. It should be further noted that the specified tolerances cannot be firmly established until actual test sections have been fabricated and tested.

2.3

CASTINGS

2.3.1 Material Specifications

Alloy ASA 356-T6 (ASTM-SG70A) Aluminum (permanent mold or sand cast machined)
Finish - cleaned, deoxidized and Oakite treated (conductive ChromiCoat L-25 per MIL-C-5541A or equivalent).

2.3.2 Fabrication Notes

Extrusion - Casting Joint: See Section 2.2.2.

Casting Skin: The skin shown covering the end and corner castings in the isometric Drawings A109 and A111 is the same skin shown in Drawing A104 as the edge extrusion skin. See Section 2.2.2.

Tolerance: If tolerances cannot be maintained sufficiently for RF shielding with the existing metal to metal contact design, an alternate approach will become necessary. A possible alternate would be to coat the contact surfaces of these castings with a conductive RF shielding silicon rubber.

2.4 WEATHER PROTECTION ROOF

2.4.1 Material Specifications

Frame:

Formed cap plate - 0.25" 6061-T6 Aluminum formed plate or equivalent.

Fabricated roof struts - 4" x 4" x 1/4" 7075-T6 extruded aluminum tube, 2" x 1 1/4" x 1/8" 7075-T6 extruded aluminum tube.

Cover Fabric: Vinyl Coated Nylon, Can-Spec-PVC 22 (22 oz/sq yd) conforming to MIL-C-43086.

Cover Retainer Extrusion: See Section 2.2.1.

Roof Frame Stay: USS Tiger Brand 1 x 19 zinc coated 3/8" steel wire rope with USS drop-forged galvanized steel 3/8" wire rope sockets and Bethlehem Steel jaw and jaw drop-forged galvanized steel turn-buckle with pins or equivalent. An alternate could be Bethlehem Purple Strand 7/16" galvanized steel wire rope and associated hardware. The required tension capability (breaking strength) is 15 kips.

2.4.2 Fabrication Notes

Fabric Retainer Straps: Tie down straps on the cover fabric (not shown) should be provided in order to secure the cover to the frame. All edges are secured by means of a rope sewn into the hem of the cover, which slips into the cover retainer extrusion and is tied at the corners.

Roof Struts: Although heavier than the extruded 7075-T6 tubing, 4" x 4" x 1/2" 6061-T6 and 2" x 1 1/4" x 1/8" 6061-T6 tubing could be used as an alternate. This alternate would be the least expensive of the two approaches.

2.5 RAISED SUPPORT FRAME

2.5.1 Material Specifications

Beams: 8WF5.9 6061-T6 Aluminum

Skirts: 20 gage (.032) 6061-T6 Bare Aluminum conforming to Specification QQ-A-327b Cond. T.

Jacks: Minimum of 10 ton capacity with an average height for jack and base support (if required) of 24 inches. (i.e. Simplex Ball-Bearing Screw Jack, Blackhawk Hydraulic Jack, etc.)

Fasteners: Skirt Panel Fastener - 3/8" Expando Grip Panel Fastener Part Number EGK 6 P S I S.
Beam Bolts - 1/2 - 13 NC structural bolts of ASA 2024-T4 alloy aluminum conforming to ASA Specification B18.2.

2.5.2

Fabrication Notes

Beam Preparation: The cross beams should be coped as shown in Drawing All6 in order to properly mate with the edge beams. All edge beams should have a thin coating of silicon rubber applied to the outside surface of the upper flange for weather protection after hole drilling. (See Drawings All6 and All7). It is desirable if this coating could also have RF shielding properties.

2.6

RF SHIELDING DOOR ASSEMBLY

The door shown is a modified RF shielding aluminum double door commercially available from Filtron Company, Inc. Alternate door assemblies are also commercially available, and could be used, however, modification may be necessary in order to incorporate the various door jams into the sandwich panel. The required opening is 6' - 8" x 6'.

2.7

RF SHIELDING AIR VENTS

2.7.1

Material Specifications

Cal Metex 16" x 16" Omnicell or equivalent.

2.7.2

Fabrication Notes

The above specified vent is a new product of the Cal Metex Corp. to be released commercially near June 1969. This vent employs a unique honeycomb design which for the first time allows aluminum to be used in vents where a magnetic field shielding effectiveness above 70 db(@ 100KHz) is required.

Alternate vent assemblies are commercially available. However, those conforming to the Class I and II magnetic field shielding requirements are made of cadmium plated steel honeycomb. In general, aluminum vents are not applicable for magnetic field attenuation above a shielding effectiveness of 70 db(@ 100 KHz). Using plated steel vents in aluminum panels

is not recommended. The difference in expansion coefficient as a function of temperature generates stress and strain in the vent-panel joint and appreciably reduces the reliability in this RF shielding joint.

2.8 FLOORING

The flooring shown in Drawing A105 is 3/4" plywood. Other materials are commercially available which are much lighter, however, plywood is the least costly. The primary function of the flooring is to prevent puncture of the inner skin of the honeycomb sandwich panel under concentrated loads. Any material which will provide puncture resistance to the skin such as floor tile, epoxy coatings, etc. should be adequate.

2.9 PANEL FASTENER

The panel fastener shown in Drawing A104 is a modified 3/8" diameter Expando-Grip Pin Fastener similar to an EGP 6 E 12 KRT Pin Fastener (yielding approximately 3800 lbs clamp up pressure) available from Adjustable Bushing Corporation, North Hollywood, California. In the modified version this fastener is stainless steel and has a specially designed thrust washer (shown in Detail A, Drawing A104). The cam handle is removed and a hex head is cast into the cam for use with any hex socket wrench for operation. The cam locks in the installed position and can be released by actuating a safety button prior to removal. The last bushing is an Expando-Lock Ring which expands to a larger diameter (shown in Detail A, Drawing A104) yielding greater tensile load capability.

2.10 EXTERNAL OVERLAP STRIPS

2.10.1 Material Specifications

Edge Overlap: 2" x 1/8" ASA 7075-T6 Bare Aluminum strip conforming to Specification QQ-A-283a, Cond. T.

2.10.2 Fabrication Notes

The external overlap strip is employed primarily for weather protection of the inner seam, thus, the inside surface of all strips should be coated with approximately .040" of silicon rubber. It would be desirable if this coating could also have RF shielding properties.

The fastener hole diameter tolerances are not as critical as those for the flanges, however, care should be taken to locate these holes so that there is no through leakage path for moisture to work into the bushing area of the fastener. However, these strips should not be insulated from the enclosure ground.

2.11 ENCLOSURE ANCHOR AND GROUNDING

All of the vertical external edge overlap strips have 1/2" copper grounding rods securely affixed to them. After assembly of the enclosure these ground rods and overlap strips simultaneously must be implanted and anchored in the terrain and secured to the enclosure (see Drawing A100).

Note: For additional discussion regarding this enclosure, consult Section III of the Final Report for Air Force Contract Number F33615-68-C-1206.

3.0 CLASS III SHIELDED ENCLOSURE - ALUMINUM

This option for the Class III Enclosure conforms to the existing drawings with no modification.

3.1 HONEYCOMB SANDWICH PANEL

3.1.1 Material Specifications

Skin: 18 gage (.040) ASA 6061-T6 Bare Aluminum conforming to Specification QQ-A-327b Cond. T.

Core: 2" Kraft paper Honeycomb conforming to MIL-H-21040, Type I, Class 1 @ .22 BTU/ft²/ F.

Adhesives: Resin adhesives per FED-STD-MMM-A-132, Type I, Class 3.

Panel Edge Extrusion: See Section 3.2.

3.1.2 Fabrication Notes

Skin Preparation: The surface of skins and panel edge extrusions should be deoxidized and then treated with conductive Oakite ChromiCoat L-25 or equivalent in conformance with MIL-C-5541A prior to fabrication.

Panel Edge Attachment: The method of attachment for the panel edge extrusion shown in the drawings is only one of several tentative approaches. With this approach an inner structural bonding adhesive and exterior RF shielding (non-structural) epoxy could be used to bond the paper honeycomb to the skin. The RF shielding epoxy could be similar to the Eccobond Solder manufactured by Emerson and Cuming, Inc.

Resistive welding or riveting could also be employed in this attachment, however, special attention should be given to possible warping effects which could render this approach infeasible. (If riveting were to be considered, they should be blind rivets and the panel edge configuration should be changed

accordingly). Rivet spacing should be kept to between one (1) and two (2) inches. In order to maintain shielding integrity, a thin coating of an RF shielding epoxy between the skins and the edge extrusion may be necessary.

Alternate configurations for the panel edge extrusion to skin attachment should be considered, depending upon varying techniques and developments in the manufacture of sandwich panels.

Lifting Eyes: Lifting eyes are required during assembly of the enclosure and must be removed during shipping and after erection. Thus, blind tapped holes are recommended at each corner of the panels. This should be considered at the time of manufacture.

3.2 EXTRUSIONS

3.2.1 Material Specifications

Alloy - ASA 6061-T6 Aluminum
Straightness (camber) - not greater than 1/16"
in any five (5) feet of length, not to exceed
1/2" overall
Twist - not greater than 1 degree in any four (4)
feet of length, not to exceed 3 degrees overall
Flatness - .004"/in of width
Surface - better than 75 RMS
Condition - extruded and straightened
Finish - cleaned, deoxidized and Oakite (conductive
ChromiCoat L-25) treated per MIL-C-5541A or equivalent

3.2.2 Fabrication Notes

Edge Extrusion End-Section: The edge extrusion shown in Drawing A118 and A119 must be machined at each end as shown in Drawing A125, Detail C. This machining allows each end to fit into the end-section as shown in Drawing A118 and A122.

3 3 BEAMS

Web and web stiffeners: 10 gage (.10 in), Roof Beam 7075-T6, Floor Beam 6061-T651, both Bare Aluminum per Specification QQ-A-3276, Cond. T. (Roof Beam Option: .20 in. 6061-T6).

Flange: 1/4" (.250), Roof Beam 7075-T6, Floor Beam 6061-T651, both Bare Aluminum per Specification QQ-A-3276, Cond. T, (Roof Beam Option: .40 in 6061-T6).

Rivets: ASA 2117-T3 1/4" and 1/8" aluminum structural rivets driven as shown (see Drawing A120).

Weather Seal: 3/8" x 1/8" Emerson and Cuming, Inc., Eccoshield SV-M (.080" thick).

Jack Mount: 2 1/2" ASA 6061-T6 Round Extruded Tube (.250" wall) conforming to Specification QQ-A-270 and AMS-4150-B, Cond. T.

3.3.2 Fabrication Notes

Seam Flange: Both the roof and floor beam seam flanges have a weather seal groove which extends across each end and along each side. This is shown only in the beam cross section drawings. Note that the roof beam rivets are countersunk in this groove. The weather seal specified above should be attached with a conductive adhesive.

Rivets: All rivets are cold driven and surfaced on the countersunk side.

3.4 WEATHER PROTECTION ROOF

3.4.1 Material Specifications

Cover Fabric: Vinyl Coated Nylon, Can-Spec-PVC 22 (22 oz/ sq yd) conforming to MIL-C-43086.

Cover Retainer Extrusion: See Section 3.2.1.

3.4.2 Fabrication Notes

Fabric Retainer Straps: Some type of tie down clip should be provided on the under side of the cover fabric in order to secure the cover to the roof beams. All edges are secured by means of a rope sown into the hem of the cover, which slips into the cover retainer extrusion and is tied at the corners (see Drawing A119, Detail A).

3.5 END SECTIONS

3.5.1 Material Specifications

Skins: 18 gage (.040) ASA 6061-T6 Bare Aluminum conforming to Specification QQ-A-327b Cond. T.

Corrugated Core: Alcoa 4" Ribbed Aluminum Industrial Siding with smooth bare finish.

Extrusions: See Section 3.2.1

Door Assembly: See Section 3.10

Air Vents: See Section 3.11

Flooring: See Section 3.7

3.5.2 Fabrication Notes

Welding: Special attention should be given to the seam and spot welding specified for these end-sections. Severe degradation of the shielding effectiveness can develop if through holes develop during the welding process.

Interchangeability: Three of the four end-sections can be interchangeable if flooring is placed on both the inside top and bottom of each of the three end-sections.

3.6 PANEL FASTENERS

The panel fastener shown in Drawing All9 is a modified 3/8" diameter Expando-Grip Pin Fastener similar to an EGP 6 E 16 KRT Pin Fastener (yielding approximately 3800 lbs clamp up pressure) available from Adjustable Bushing Corporation, North Hollywood, California. The cam handle is removed and a hex head is cast into the cam for use with any hex socket wrench for operation. The cam locks in the installed position and can be released by actuating a safety button prior to removal. The last bushing is an Expando-Lock Ring which expands to a larger diameter yielding greater tensile load capability.

3.7 FLOORING

The primary function of the flooring is to prevent puncture of the inner skin of the honeycomb sandwich panel under concentrated loads. Any material which will provide puncture resistance to the skin such as floor tile, epoxy coatings, plywood, etc. should be adequate.

3.8 JACKS

Minimum of 10 ton capacity with an average height for jack and base support (if required) of 24 inches. (i.e. Simplex Ball-Bearing Screw Jack, Blackhawk Hydraulic Jack, etc.)

3.9 SKIRTS

20 gage (.032) 6061-T6 Bare Aluminum conforming to Specification QQ-A-37b Cond. T.

3.10 RF SHIELDING DOOR ASSEMBLY

The door shown is a modified RF shielding aluminum door commercially available from Filtron Company, Inc. Alternate door assemblies are also commercially available and could be used. However, modification may be necessary in order to incorporate the various

door jams into the sandwich panel. The required opening is 6' - 8" x 3'. Depending on the particular door jam and door used, sufficient structural reinforcement should be given to the frame to distribute the door loads, as shown in Drawing A124 by the dotted lines.

3.11 RF SHIELDING AIR VENTS

3.11.1 Material Specifications

Tecknit EMC Teckcell Part Number 30 23 16 x 16 03 04 or equivalent.

3.11.2 Fabrication Notes

Two approaches to installation of these vents have been considered; first, to install the vents permanently in the honeycomb sandwich panel (shown in Drawing A123) and second, to install replaceable vents in the completed sandwich panel (specified above). Either approach should be adequate for RF shielding.

Note: For additional discussion regarding this enclosure, consult Section III of the Final Report for Air Force Contract Number F33615-68-C-1206.

APPENDIX III
SECTION C
SPECIFICATION REFERENCES
STRUCTURAL DESIGN CALCULATIONS

Presented below are the structural design calculations for the three classes of shielded enclosures. The calculations for each class of enclosure are subdivided first by enclosure components and then by design criteria. Two options for the Class I enclosure are given. Each option is presented separately and references are given for the appropriate drawings. The following section numbers are the Specification Reference Numbers noted in the title block of each drawing.

1.0 CLASS I SHIELDED ENCLOSURE - STEEL OPTION

This option for the Class I enclosure conforms to the existing drawings with no modifications. See 1.12 for aluminum option.

1.1 HONEYCOMB SANDWICH PANELS

1.1.1 Roof Panels

Assumptions: Flat plate of uniform thickness supported on all edges (plate theory). Edges assumed to be clamped or simply supported, whichever creates the most severe state of stress for a given point.

Bending Moment at the Center of Each Side (M_1) - assuming clamped edge condition.

$$M = \beta q a^2 \text{ (in-lb/in of width)} \quad (1)$$

where M = bending moment for flat plate per unit width of section analyzed.

β = constant dependent upon plate geometry and support conditions.

q = uniformly distributed load, perpendicular
to plane of a flat plate (psi)
a = unsupported span (plate theory) (in)

for $\beta_1 = .0153$
 $q_1 = .403 \text{ psi (58 psf)}$
 $a_1 = 240 \text{ in.}$

$$M_1 = B_1 q_1 a_1^2 = 1,190 \text{ in-lb}$$

Bending Moment at Center of Panel (M_1) - assuming a simply supported edge condition.

from equation (1), if $\beta_2 = .0470$

$$M_2 = \beta_2 q_1 a_1^2 = 1,111 \text{ in-lb}$$

Stress in Panel Skins (f'_1) - for special case of sandwich panel.

$$f' = \frac{M}{td} \quad (\text{psi}) \quad (2)$$

where t = skin thickness (in)
d = distance between skin centroids (in)

for $M = M_1$
 $t = 0.028 \text{ in}$
 $d = 2.028 \text{ in}$

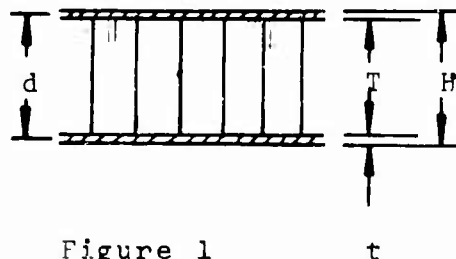


Figure 1

$$f'_1 = \frac{M_1}{td} = 20,959 \text{ psi}$$

Allowable tension stress for 0.028 in. thick steel skin (F_S)

$$F = .60 F_y \quad (\text{psi}) \quad (3)$$

where F_y = the material yield point stress (psi).
 For A446 grade C steel $F_y = 40,000$ psi
 and $F_S = 24,000$ psi

Shear in the Panel Core (v) for special case of sandwich panel supported on all edges.

$$v = \frac{2\gamma qa}{H + T} \quad (4)$$

where γ = a constant dependent upon aspect ratio
 H = total panel thickness (in)
 T = core thickness (in)

for $\gamma_S = 0.420$ (square panel)

$H = 2.056$ in
 $T = 2.0$ in
 $a = 240$ in
 $q_1^1 = .403$

$$v_1 = \frac{2 \gamma_S q_1 a}{H + T} = 19.8 \text{ psi}$$

Deflection at the Center of a Panel (y_1)

$$y = \frac{\alpha_1 q a^4}{D} + \frac{\alpha_1 \alpha_2 qa^2 \pi^2}{T G_c} \quad (5)$$

where α_1 and α_2 = constants based upon panel aspect ratio

D = flexural coefficient dependent upon material and support conditions (psi/inch of width)

G_c = core shear modulus (psi)

for $\alpha_1 = 0.004$
 $\alpha_2^1 = 1.83$

$D = 1.67 \times 10^6$ in-lbs/in of width
 $G_c = 6706$ psi

$$y_1 = \frac{\alpha_1 q_1 a^4}{D} + \frac{\alpha_1 \alpha_2 q_1 a^2 \pi^2}{T G_c} = 3.33 \text{ in}$$

1.1.2 Floor Panels

Assumptions: Flat plate of uniform thickness supported on two edges (beam theory). The applied loads may not necessarily be uniformly distributed and thus all calculations are based on the most critical condition for uniformly distributed loads. Thus, edges are assumed to be simply supported.

Bending Moment at the Center of a Single Span (M_3)

From equation (1) for $q_2 = 1.11$ psi (160 psf),
 $a_2 = 78$ in., and $\beta_3 = 20.125$

$$M_3 = \beta_3 a_2^2 q_2 = 845 \text{ in-lbs}$$

Stress in Panel Skin (f'_2).

From equation (2) for $M = M_3$,

$$f'_2 = \frac{M}{dt} = 14,881 \text{ psi}$$

From equation (3), using A446, Grade C Steel
 $F_S = 24,000$ psi.

Since from equation (2) for f'_2 , $f'_2 < F_S$, .028 in.
steel skins are adequate for floor panel loads.

Shear in Panel Core (v').

Assuming two edges support

$$v' = 1.67 \frac{q a}{H+T} \text{ (psi)} \quad (6)$$

$$v' = 1.67 \frac{q_2 a_2}{H+T} = 35 \text{ psi}$$

Deflection at the Center of Panel (y').

$$y' = \frac{5 q a^4}{384 D} + \frac{q a^2}{8 U} \quad (\text{in.}) \quad (7)$$

where U = shear stiffness per in. of width from
 $U = G_c (H+T)/2$ lbs/in per in. of width (8)

for $U = 13.6 \times 10^3$ lbs/in.

$$y' = \frac{5 q_2 a_2^4}{384 D} + \frac{q_2 a_2^2}{8 U} = 0.38 \text{ in.}$$

1.1.3 Wall Panels

Assumptions: Flat plate of uniform thickness supported on two edges (beam theory). Edges assumed to be clamped or simply supported.

Basic Wind Load (q_3).

The theoretical wind pressure can be determined from

$$\text{the equation, } q = 0.0025 s^2 \text{ (psf)}$$

where s is wind speed in mph.

The basic wind load equation, adjusted for building shape and gust effects, is

$$q = 0.0042 s^2 \text{ (psf)} \quad (9)$$

Thus, for a 100 mph wind,

$$q_3 = .0042 \times 100^2 = 42 \text{ psf } (.292 \text{ psi})$$

Bending Moment at the Center of a Simple Span due to wind load (M_4)

Using eq. (1) where $q = q_3$, $a_3 = 126$ in., and $\beta_3 = .125$

$$M_4 = \beta_3 q_3 a_3^2 = 579 \text{ in-lb}$$

Stress in the Panel Skin Due to wind loading (f'_3)

Using eq. (2) for $M = M_4$

$$f'_3 = \frac{M_4}{td} = 10,193 \text{ psi}$$

Axial Stress in Panel Skin due to vertical loads (f_{a_1})

$$f_a = \frac{P}{A} \quad (\text{psi/in. of width}) \quad (10)$$

Where P = applied axial force (lbs/unit width of section analyzed)

A = cross sectional area of skins analyzed
(equals bt for sandwich panel skin stress)

t = panel skin thickness (in)

b = width (in.) of beam, column, or equivalent section analyzed.

With roof dead and live load, and wall dead load applied,

$$P_1 = 55.3 \text{ lbs/in.}, b = 1.0 \text{ in.},$$

$$\text{and } t = .028 \text{ in.},$$

$$\text{then } f_{a_1} = \frac{P_1}{2bt} = 998 \text{ psi}$$

Allowable Compression Stress in Steel Skin due to vertical loads (F_{a1}), per American Institute of Steel Construction when $Kl/r > C_c$

$$F_a = \frac{1.49 \times 10^8}{(Kl/r)^2} \text{ (psi)} \quad (11)$$

where $r = \sqrt{\frac{I}{A}}$ (in) = radius of gyration

k = effective length factor

l = unsupported length (in.) of column

I = rectangular moment of inertia with respect to neutral axis (in.⁴)

C_c = column const.

For a 2 in. panel core thickness and 0.028 in. thick panel skins,

$$I = .0578 \text{ in.}^4$$

$$A_1 = .056 \text{ in.}$$

$$K = 1.0$$

$$l_1 = 126 \text{ in.}$$

$$r_1 = 1.016 \text{ in.}$$

$$\text{and } F_a = \frac{1.49 \times 10^8}{(Kl_1/r_1)^2} = 9,688 \text{ psi}$$

Determination for the Adequacy of the Wall Panels per AISC interaction stress eqs. for two cases of joint rigidity.

Assumption (Case 1): wind blowing uniformly on simply supported wall panel.

When $f_a/F_a \leq 0.15$, the structural section subjected to bending and axial stresses simultaneously is within the allowable stress range when, $\frac{f}{F} + \frac{f_a}{F_a} \leq 1.0$ (12)

For A446, Grade C steel and from eqs.

$$\frac{f'_3}{F_s} + \frac{f_{a_1}}{F_{a_1}} = 0.526 < 1.0$$

and therefore this section for this specified condition is adequate per AISC standards.

The adjusted bending stress for combined axial and bending stress is defined by,

$$\psi = \frac{\psi_0}{1 - \frac{P}{P_{cr}}} \quad (13)$$

from "Design and Analysis" (7)

where ψ_0 = bending stress

P_{cr} = Euler critical buckling load defined by

$$P_{cr} = \frac{\pi^2 D}{l^2 \left(1 + \frac{\pi^2 D}{l^2 U} \right)} \quad (14)$$

For A446 steel and a 2 inch panel core,

$$D = 1.67 \times 10^6$$

$$U = 13.6 \times 10^3$$

$$l_1 = 126 \text{ in.}$$

Thus, $P_{cr} = 1124 \text{ lbs.}$

And therefore, since $P_1 = 55.3$ (eq. 10), and

$$\psi_0 = f'_2 = 14,881 \text{ psi}$$

$$\psi = \frac{f'_2}{1 - \frac{P_1}{P_{cr}}} = 15,469 \text{ psi}$$

Therefore the section per the above reference is adequate since $\psi < F_s$.

Assumption (Case 2): all panel to panel joints considered to have moment resisting connections.

The combined axial and bending stresses determined above were based on bending stresses due to wind loads and axial stresses due to roof dead and live loads. These loads may be combined with the bending stresses induced in the wall due to floor dead and live loads and roof dead loads. It is not necessary to combine roof live loads with wind loads under established engineering standards.

Loading conditions and assumed bending moment distributions are shown below.

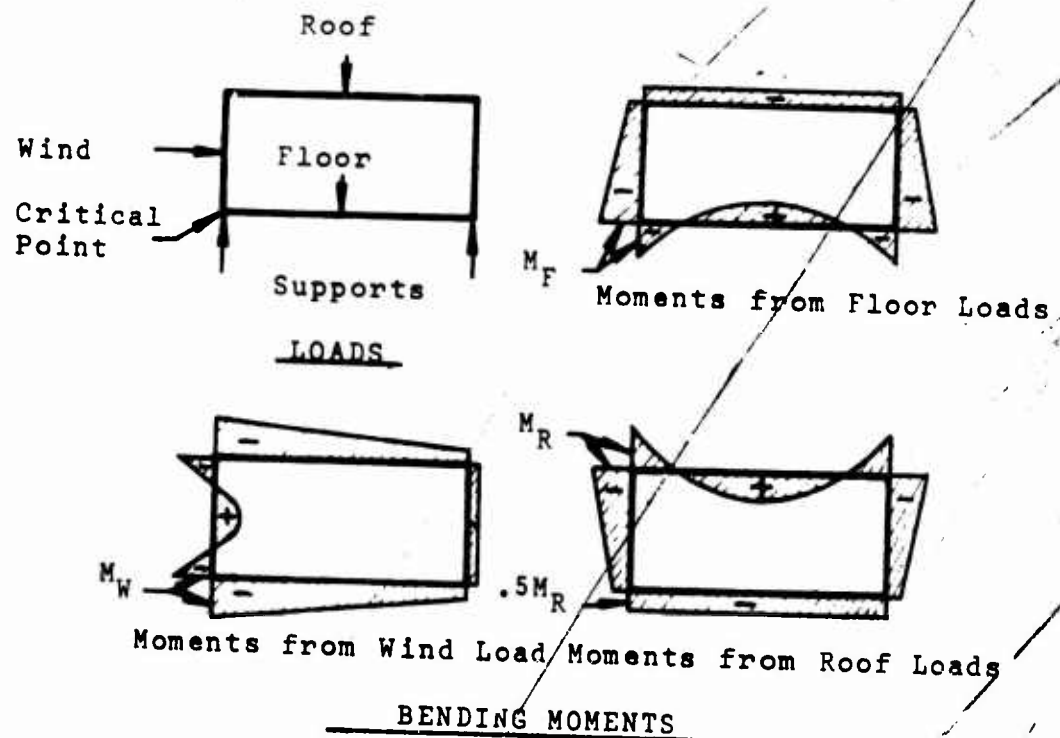


Figure 2

Critical Point Moment (M_c)

$$M_c = 0.5 M_R + M_F + M_W \quad (15)$$

where moments are as shown above

$$\text{For } M_R = \left(\frac{8}{58}\right) M_1 = 164 \text{ in-lbs.}$$

$$M_F = \left(\frac{3}{4}\right) \left(\frac{8}{12}\right) M_3 = 422 \text{ in-lbs.}$$

$$M_W = \left(\frac{3}{4}\right) \left(\frac{8}{12}\right) M_A = 290 \text{ in-lbs.}$$

where the factor of 8/12 is to adjust the simple span moment to a fixed end moment and the factor of 3/4 is to conservatively estimate the distributed joint moments.

Thus, $M_c = 794 \text{ in-lbs.}$

Stress in the Wall Panels at the Critical Point (f_c).

Using eq. (2) where $M = M_c$, $d = 2.028 \text{ in.}$ and $t = 0.028 \text{ in.}$

$$f_c = \frac{M_c}{td} = 13,983 \text{ psi}$$

Axial Stress in Wall Panels due to the axial dead loads of the roof and wall

Using eq. (10) for $P = P_2 = 13.66 \text{ lbs/in of width}$

$$f_a = 244 \text{ psi}$$

Combining stresses for maximum condition of floor (dead and live), roof (dead), and wind loads,

from eq. (12),

$$\frac{f_c}{F_s} + \frac{f_a}{F_{a_1}} = 0.608 < 1.0$$

and therefore section is adequate for case 2, per AISC standards for maximum stress condition.

From eq. (13), where $\psi_0 = f_c = 13,983$ psi,
 $P = P_2 = 13.66$ lbs/in

$$\psi_c = \frac{f_c}{1 - \frac{P_2}{P_{cr}}} = 14,154 \text{ psi} < 24,000 = F_s$$

thus, section is also adequate per Ref. 7 since $\psi_c < F_s$.

1.2 EXTRUSIONS

1.2.1 Panel Edge Extrusion

Assumptions: The following calculations are based on the most severe loading case - roof panel edge. The core is considered rigidly fixed to the roof panel edge flanges and skins.

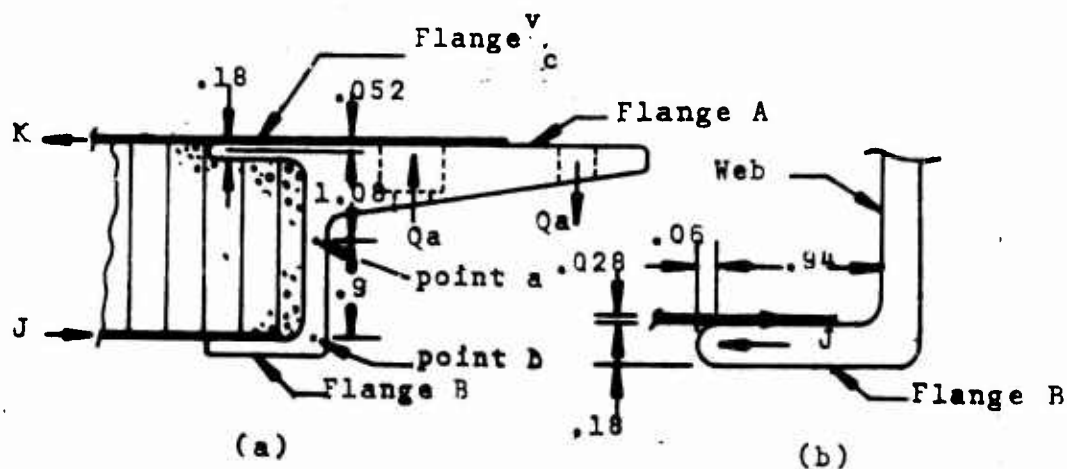


Fig. #3

Tension or Compression membrane force in Roof Panel
Skins (P'_1)

$$P' = \frac{M}{L} \quad (16)$$

where L = the moment arm

For $M = M_1 = 1,190$ in-lbs (eq. 1) and

$L_1 = d = 2.028$ in.,

$$P'_1 = \frac{M_1}{L_1} = 586.8 \text{ lbs/in. of width}$$

Bending Moment (M'_1) in Flanges B and C due to the
Eccentricity (e) of the Skins with respect to centerline
of each flange

$$M' = \frac{P' L'}{\rho} \quad (17)$$

where P' = applied load, tension or compression in
a section

ρ = a constant dependent open load distribution

L' = beam span

From Fig. 3a, and eq. (16) $L'_1 = e = .104$ in. and $\rho = 1$;

$$M'_1 = P'_1 e = 61 \text{ in-lbs}$$

Section Modulus of Flange B or C as equivalent beam (S_1)

$$S = \frac{b k^2}{6} \quad (18)$$

Let the equivalent beam width of the section be $b = 1$ in., and from Figure 3b let $k_1 = 0.94$, the beam depth or equivalent with rectangular cross section such that,

$$S_1 = \frac{k_1^2}{6} = .147 \text{ in.}^3$$

Stress in Flanges B and C assuming core to be tributary to section modulus, assuming support on two edges

$$f = \frac{M'}{S} \quad (19)$$

where S is the equivalent beam section modulus,

For $S = S_1$ from eq. (18)

$$f_1 = \frac{M'_1}{S_1} = 415 \text{ psi}$$

Note that f_1 also represents the minimum ultimate tensile strength for both the core and adhesive.

Stress in Flanges B and C assuming core not to be tributary to section modulus.

From equations (18) and (19), for $S = S_2$ = section modulus of flanges B and C acting as cantilever beams with a span of 0.94 in., and $k_2 = 0.18$ in.,

$$S_2 = \frac{k_2^2}{6} = .0054 \text{ in}$$

and

$$f_2 = \frac{M_1'}{S_2} = 11,302 \text{ psi}$$

Axial Stress in Flanges B and C due to the tension and compression in the flanges

$$f_a' = \frac{P}{A} \quad (20)$$

where A is the area that the tension or compression P' is distributed over.

Thus,

$$f_a' = \frac{P_1'}{b k_2} = 3,260 \text{ psi}$$

where $A_2 = b_2 k_2 = .18 \text{ in.}^2$ and $P = P_1'$

Maximum Tensile Stress in Flanges B and C assuming most severe cases of bending and axial stresses.

$$f_m = f_a' + f_2 = 14,562 \text{ psi}$$

Buckling Stress in Flange B or C due to axial compression.

Using the slenderness ratio, l/r where $r = ug$ (21)
 and l = effective column length, in.
 u = geometrical constant for a rectangle
 r = radius of gyration, in.

For $l_2 = 0.94 \text{ in}$; $u = .289$; $g = k_2 = .18 \text{ in}$.

$$\frac{l_2^2}{r_2^2} \approx 18$$

By inspection of this $\frac{1}{F}$ ratio it is evident from AISC standards the allowable buckling stress is much greater than the actual stress determined above.

Bending Moment at Point "a" in Figure 3a (assuming 100% core-flange fixity) (M'_2)

Assuming half of the moment due to force J to act at point "b", the Bending moment using equation (17)

$$M'_2 = \frac{1}{2} P'_1 L'_2 = .323 \text{ in-lb}$$

where $L'_2 = 1.1 \text{ in.}$, and $\rho = 2$,

Flexural stress at Point "a" due to moment M'_2 , (f_3)

From equation (18), for $b = 1 \text{ in.}$ and $k_3 = 0.25 \text{ in.}$

$$S_3 = \frac{b k_3}{6} = .0104 \text{ in}^3$$

where $k_3 = \text{thickness of the web}$

And thus, from equation (19)

$$f_3 = \frac{M'_2}{S_3} = 31,029 \text{ psi}$$

Flexural Stress at Point "a" (f_4) (assuming no core-flange fixity)

Moment due to force P'_1 all at "a",

$$M'_3 = 2M'_1 = 645 \text{ in-lbs}$$

and

$$f_4 = \frac{M'_3}{S_3} = 2f_3 = 62,058 \text{ psi}$$

Web Thickness (k'_3) required for various yield stress with no web fixity at flange B.

Combining equation (18) and (19), and solving for k , allowing $f \rightarrow F_{a_2}$

$$k'_3 = \frac{6M'_3}{b F_{a_2}} \quad \text{or} \quad \frac{M'_3}{.11 F_y} \quad (22)$$

assuming $F_{a_2} = .66 F_y$

$$\text{Thus, } k'_3 = \frac{77.6}{F_y} \quad (23)$$

Typically if,

$$F_y = 50 \text{ KSI, } k'_3 = 0.345 \text{ in}$$

$$F_y = 75 \text{ KSI, } k'_3 = 0.280 \text{ in}$$

$$F_y = 100 \text{ KSI, } k'_3 = 0.244 \text{ in}$$

Shear in Flanges B & C due to roof loads ($v_{F''}$)

$$v_{F''} = (1/2)v'' = (1/2)\phi q_1 a_1 \quad (24)$$

since roof panel shear is given by

$$v'' = \phi q a$$

where ϕ = constant dependent on geometry and method of support

For $\phi = .338$, $v'' = 32.69$ lbs/in

$$v_F'' = 16.35 \text{ lbs/in}$$

Bending Moment in Flanges B & C due to Roof Panel Shear (M_S)

$$M_S = v_F'' L_3' = 7.68 \text{ in-lbs} \quad (25)$$

where $L_3' = .47 \text{ in}$

Flexural Stress in Flanges B & C due to moment M_S (f_5)

Using equation (19), with $f = f_5$, $M' = M_S$, $S = S_3$;

$$f_5 = \frac{M_S}{S_3} = 1,422 \text{ psi}$$

Flexural Stress in Flange A (f_6)

Moment in Flange A from equation (1), $M_1 = 1190$ in-lbs

Thus, with no fastener holes, from equation (19),

$$f_6 = \frac{M_1}{S_4} = 17,989 \text{ psi}$$

where S_4 , from equation (18),

$$S_4 = \frac{b k_4^2}{6} = .06615 \text{ in}^3$$

where $k_4 = 0.63 \text{ in.}$

Therefore, the Flexural Stress, considering fastener holes,

$$f_7 = R_H F_6 = 21,587 \text{ psi}$$

where R_H = ratio of flange section area with no holes to the flange section area with holes or $R_H = 1.2$.

1.2.2 Edge Extrusion

Edge Flange Extrusion analysis is identical with Panel Flange A analysis.

Compression forces on the Intermediate Edge Extrusion (I.E.E.)
(P'_2)

From equation (16) and Figure 4, for $L_2 = 1.83 \text{ in.}$,

$$P'_2 = \frac{M_1}{L_2} = 651.3 \text{ lbs}$$

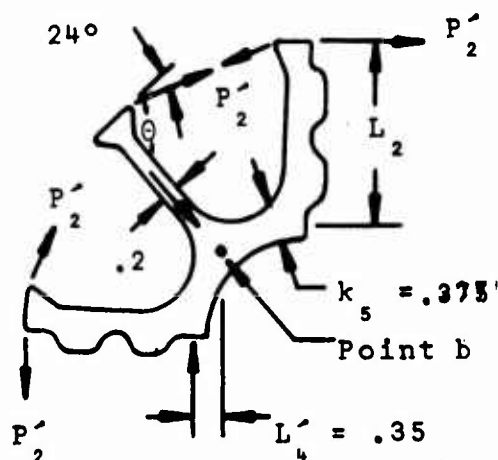


FIGURE 4

Bending Moment for I.E.E. due to P'_2 , M'_4 about point b of Figure 4.

Using equation (17), for P' and $L' = L'_4 = .35$ in;

$$M'_4 = P'_2 L'_4 = 228 \text{ in-lbs}$$

Stress in the I.E.E. at point in Figure 4 (f_8)

Since from equation (18), for $b = 1$ in and $k_5 = .375$ (web thickness),

$$S_5 = \frac{b k_5^2}{6} = .0234 \text{ in}^3$$

then using equation (19), for $M' = M'_4$ and $S = S_5$,

$$f_8 = \frac{M'_4}{S_5} = 9,744 \text{ psi}$$

Axial Stress in center strut of I.E.E. (f'_{a_2})

Using equation (20), where P'_3 (the web reaction force) is given by

$$P'_3 = 2P'_2 \cos \theta_1 = 530.4 \text{ lbs}$$

where $\theta_1 = 66^\circ$ from Figure 4

and $A_3 = b k_6 = 0.20 \text{ in}^2$, $k_6 = .2$ in. is the web thickness, and $b = 1$ in.

$$\text{then } f'_{a_2} = \frac{P'_3}{A_3} = 2652 \text{ psi}$$

Allowable Stress in center strut of I.E.E. (F'_{a_3})

Since $F_a \propto (1/r)$; for $l_3 = 1.7$ in. and

$r_2 = \mu k_6 = .0578$ in.

$$\frac{l_3}{r_2} = 29.4$$

From AISC standards this corresponds to an

$$F'_{a_3} \approx 20,000 \text{ psi}$$

1.3 CASTINGS

The corner and extrusion end castings sustain only a small calculable stress from the specified structural loads. Selection of material for these castings is based on anticipated stress occurring during fabrication, transportation, and enclosure erection and disassembly.

1.4 WEATHER PROTECTION ROOF

Assumptions: Although the specified load for the enclosure roof is 50 psf, the weather protection roof (false roof) is designed for a 32 psf load (30 psf live snow load + 2 psf dead load). The enclosure roof (actual roof) however, is designed for a 58 psf load (50 psf specified + 8 psf additional material dead load).

1.4.1 Diagonal Struts

Bending Moment for each strut assuming the total load to be triangularly distributed with a peak at mid-span.

Compression in each strut due to roof loads (32 psf) (P'_5)

The beam reaction, as shown in Figure 5a, is

$$R = \frac{2}{3} P'_4 = 1493 \text{ lbs}$$

Summing the moments about point c in Figure 5a,

$$P'_5 = \frac{2 P'_4 \cos \theta_2}{3 \tan \theta_2} + P'_4 \sin \theta_2 = 8010 \text{ lbs} \quad (28)$$

where $\theta_2 \approx 11^\circ$

Allowable Compression Stress of each strut (F_{a_4})

For a tubular strut 4" x 4" x 3/16" wall, the slenderness ratio from equation (21), is

$$\frac{l_4}{r_3} = 113$$

where $r_3 = 1.54 \text{ in.}$ and $l_4 = L'_5 / \cos 11^\circ = 177 \text{ in.}$

Thus, from AISC standards, this corresponds to

$$F_{a_4} \approx 11,290 \text{ psi}$$

Compression Stress in each strut (f'_{a_3})

From equation (20 and P'_5

$$f'_{a_3} = \frac{P'_5}{A_5} = 2,920 \text{ psi}$$

where $A_5 = 2.74 \text{ in}^2$

Allowable Bending Stress of each strut (F_{b_1})

For 4" x 4" x 3/16" steel strut $F_{b_1} = 33,000$ psi

Bending Stress in each strut (f_9)

From equation (19), for $M = M'_5$ and $S = S_6$,

$$f_9 = \frac{M'_5}{S_6} = 19,810 \text{ psi}$$

where $S_6 = 3.23 \text{ in}^3$ for strut section

Determination for the Adequacy of roof struts per AISC interaction stress equation.

From equation (12), combining axial and bending stresses,

$$\frac{f'_a}{f_{a_4}} + \frac{f_9}{f_{b_1}} = .359 < 1.0$$

and therefore section is adequate.

1.4.2 Roof Frame Stay

Tension in Cable due to the roof load (32 psf) tributary to each strut (P'_6)

From Figure 5,

$$P'_6 = \frac{2 \sin 45^\circ}{3 \tan 11^\circ} P'_4 = 5,430 \text{ lbs} \quad (29)$$

Bethlehem Strand, 19 wire, 7/16" dia., improved plow steel has a breaking strength of 14,500 lbs. Thus, this cable section is adequate, with a safety factor of 2.7.

1.4.3 Cover Fabric

Fabric Tear Resistance assuming most critical condition of tear line a-a (Q max).

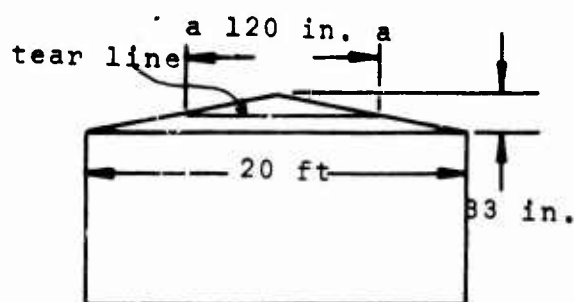


FIGURE 6

From Figure 6, the force on tear line due to wind load (most severe case),

$$P'_7 = q_3 A_6 = 1155 \text{ lbs}$$

$$\text{where } A_6 = \frac{1}{2} jh = 3950 \text{ in}^2 \quad (30)$$

Thus, across tear line a-a, the tear resistance is

$$Q \text{ max} = \frac{P'_7}{j} = 9.63 \text{ lbs/in (115.5 lbs/ft)}$$

1.4.4 Cover Retainer Extrusion

Moment at point a of retainer extrusion

$$M'' = P' L \quad (31)$$

For $L_3 = 0.75 \text{ in.}$ and $P'_8 = Q \text{ max.}$

$$M''_1 = P'_8 L_3 = 7.22 \text{ in-lbs}$$

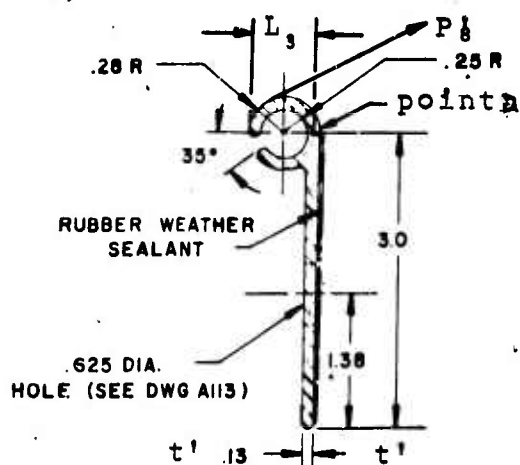


FIGURE 7

Thickness (t') of Extrusion

The allowable bending stress when due to a wind loading condition,

$$F_b = .66 \omega F_y \quad (32)$$

where $\omega = 1.33$ and F_y = yield stress

Thus, for $F_y = 40,000$ psi

$$F_{b_2} = 35,200 \text{ psi}$$

From equation (22), the minimum thickness for the extrusion is

$$t' = \frac{6 M_1'}{F_{b_2}} = .0346 \text{ in.}$$

where $b = 1$ in.

Therefore a 0.125 in. thickness is adequate with a 3.6 safety factor.

1.5 RAISED SUPPORT FRAME

Assumptions: Framework is composed of steel beams, spanning between supports provided by adjustable jacks.

1.5.1 Interior Floor Beams

Bending Moment of Interior Floor Beams (M_5)

Using equation (1), with $q_1' = q_5$, $b_1' = 90.5$ lbs/in,
where $q_5 = 1.146$ psi (165 psf), $b_1' = 79$ in. (tributary
width for floor load), $a_4 = 117$ in. and $\beta = \beta_3 = .125$

$$M_5 = \beta_3 q_1' a_4^2 \approx 154,857 \text{ in-lbs}$$

Bending Stress in Interior Floor Beams (f_{10}).

Consider an 8 in. wide flange beam at 17 lbs/ft (8WF17) of ASTM A36 steel with a section modulus S_7 of 14.1 in³.

From equation (19), for $M' = M_5$

$$f_{10} = \frac{M}{S_7} = 10,983 \text{ psi}$$

Allowable bending stress per AISC standards (F_b')

$$F_b' = \frac{12 \times 10^6}{L'^2 k/A_f} \text{ (psi)} \quad (33)$$

where L' = unbraced length of beam compression flange (in.)

d = beam depth (in.)

A_f = area of flange (in²)

for $L_1' = 117$ in, $\frac{k}{A_f} = 4.95 \text{ in}^{-1}$

$$F_{b_1} = \frac{12 \times 10^6}{L_1^2 k/A_f} = 20,720 \text{ psi} > 10,983 \text{ psi}$$

therefore section is adequate.

1.5.2 Exterior Floor Beams

Considering the tributary area for the roof, floor and wall loads, the load on the beam per inch

$$q_6 = 99.6 \text{ lbs/in}$$

By comparison with the analysis for the interior beams, it can be shown the same 6WF17 beam is also adequate for this load.

1.6 R.F. SHIELDING DOOR

1.6.1 Vertical Jamb

Bending moment of vertical jamb about the B axis (M'_6)

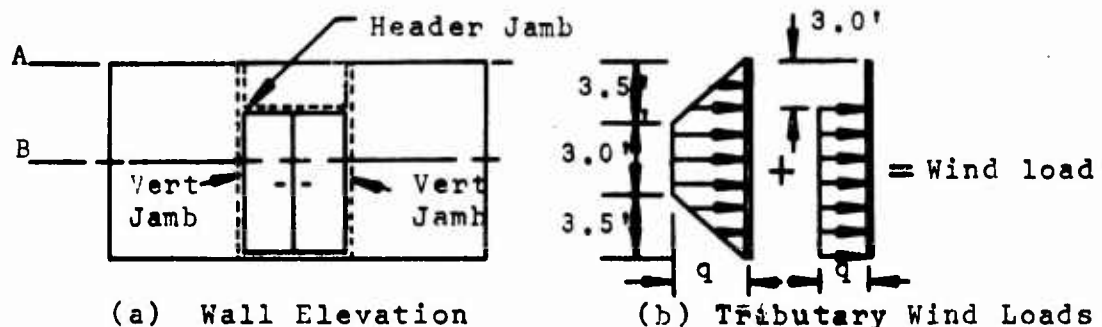


FIGURE 8

By assuming the moments about the A axis due to wind loading ($q_3 = .292 \text{ psi}$) and solving for the reaction force R_F ,

$$R_F = 1108 \text{ lbs}$$

Summing moments about the B axis using reaction force R_F about center of jamb,

$$M'_6 = 38,546 \text{ in-lbs}$$

Bending Stress of Vertical Jamb (f_{11})

Using equation (19),

$$f_{11} = \frac{M'_6}{S_8} = 32,340 \text{ psi}$$

where $S_8 = 1.19 \text{ in}^3$ for section shown below

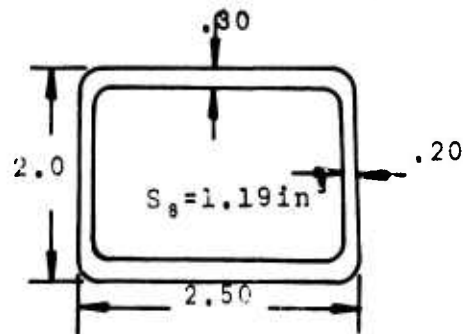


FIGURE 3

Allowable Bending Stress (F_{b_3})

Per AISC standards, allowing a 1/3 increase for wind load condition,

$$F_{b_3} = 44,000 \text{ psi}$$

since $f_{11} < F_{b_3}$, section is adequate.

1.6.2 Horizontal Header

Bending moment of header member, assuming wind load increasing uniformly to center of member (M_6).

The distributed load on header due to wind loading on tributary area,

$$q'_2 = b'_2 q_3 = 5.25 \text{ lbs/in.} \quad (34)$$

where $b'_2 = 18 \text{ in.}$ = width of tributary loading area

Using equation (1), for $M = M_6$, $\beta_3 = .125$,

$q = q'_2$, and $a_5 = 72 \text{ in.}$

$$M_6 = \beta_3 q'_2 a_5^2 = 3402 \text{ in-lbs}$$

Bending stress of header member (f_{12})

Using equation (19), for $M' = M_6$

$$f_{12} = \frac{M_6}{S_9} = 8,237 \text{ psi}$$

where $S_9 = .413 \text{ in}^3$ for section shown below

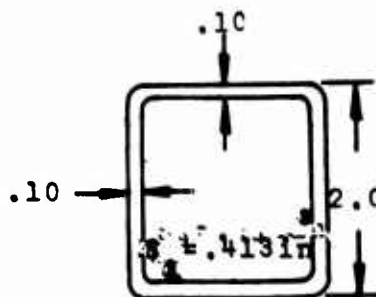


FIGURE 10

Allowable Bending Stress (F_b)

Per AISC as above, the allowable stress is $F_b = 44,000$ psi and thus the section is adequate since $f_{12} < F_b$.

1.7 R.F. SHIELDING AIR VENTS

No specific structural calculations required.

1.8 FLOORING

Upon further definition of puncture loads, specific calculations for puncture resistance and load distribution can be made.

1.9 PANEL FASTENERS

Axial Force in Fasteners (Q_a)

$$Q_a = \frac{M_1}{z} = 656.7 \text{ lbs/in.} \quad (35)$$

where z = the separation between the two rows of fasteners = 1.812 in.

For a 3 in. separation along the extrusion between fasteners, the axial force in each fastener is,

$$Q_f = 3 Q_a = 1970 \text{ lbs/fastener}$$

1.10 EXTERNAL OVERLAP STRIP

Assumptions: Consider strip as a beam on an elastic foundation. Nominal dimensions of strip: 2" x .125"
Net thickness of strip (without galvanize): .123 in.
Rubber seal to have spring constant $p_o = 8,333 \text{ lbs/in}^3$

Deflection of compound beam - rubber and metal (y_1'')

$$y_1'' = \frac{P' \lambda}{2 p} A_{\lambda x} \quad (36)$$

$$\text{where } A_{\lambda x} = e^{-\lambda x} (\cos \lambda x + \sin \lambda x) \quad (37)$$

$$\text{for } \lambda = \sqrt[4]{\frac{P}{4EI}} \quad (38)$$

p' = applied force on elastic foundation due to fasteners

x = distance from deflection point to point of applied force

I' = moment of inertia for a beam or equivalent

p = spring constant of rubber foundation for a width $b_3' = 2''$ of strip = $2p_0$

The moment of inertia of the steel strip

$$I' = \frac{b_3' k_7^3}{12} = 3.11 \times 10^{-4} \text{ in}^4$$

where $k_7 = 0.123 \text{ in.}$ and $b_3' = 2.0 \text{ in.}$

Thus, for $E = 2.9 \times 10^7 \text{ psi}$ for steel and $p = 16,666 \text{ psi}$, from equation (38),

$$\lambda = \sqrt[4]{\frac{P}{4EI}} = .8244 \text{ in}^{-1}$$

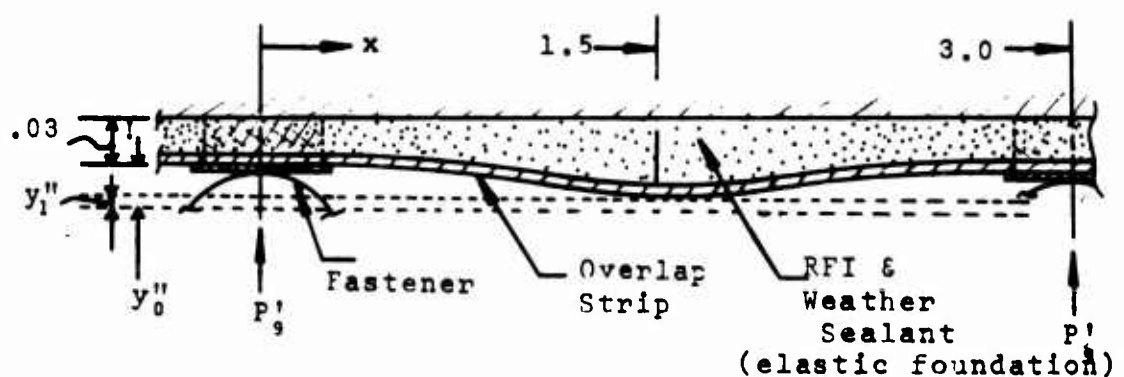


FIGURE 11

Therefore, as shown in Figure 11, at the fastener ($x=0$), $y''_0 = .010$ and from equation (36),

$$P'_9 = \frac{2 P y''_0}{\lambda} = 404.3 \text{ lbs}$$

since $A_{\lambda x} \rightarrow 1$ at $x=0$.

At $x = 1.5$ in. (mid-span) and $A_{\lambda x} = .3677$,

$$y''_1 = \frac{P'_9 \lambda}{P} A_{\lambda x} = 2 y''_0 A_{\lambda x} = .0074 \text{ in.} \quad (39)$$

Since y''_1 results from the applied force P'_9 at both ends of the span.

The pressure on the rubber sealant at $x = 1.5$ in. for a hypothetical area $.1" \times 2"$, compressed $.0074$ in. ($A_7 = .00148 \text{ in}^3$)

$$P'_{10} = p_0 A_7 = 123.3 \text{ lbs}$$

Bending moment of metal strip (M''_2)

$$M''_2 = \frac{P'_9}{4\lambda} C_{\lambda x} = 22 \text{ in-lbs} \quad (40)$$

where $C_{\lambda x} = e^{-\lambda x} (\cos \lambda x - \sin \lambda x) = .1797$
evaluated at $x = 1.5$ in.

Bending stress of metal strip (f_{13})

Using equation (19), for $M' = M''_2$

$$f_{13} = \frac{M''_2 c}{I'} = 4,357 \text{ psi}$$

where $S_{10} = \frac{I'}{c}$ and $c = \frac{k_7}{2} = .0615 \text{ in.}$

and $I' = 3.11 \times 10^{-4} \text{ in}^4$

Using A446, Grade C steel, as in equation (22)
the allowable bending stress is

$$F_b = .66 F_y = 26,400 \text{ psi}$$

where $F_y = 40,000 \text{ psi}$

Thus section is adequate since $f_{13} < F_b$.

1.11 ENCLOSURE ANCHORING

1.11.1 Overturning Forces

Total wind force on enclosure (maximum load) (P_w).

Wall wind force is, $P'_{11} = q_1 A_9 = 8,400 \text{ lbs.}$

where $A_9 = \text{tributary area of wall} = 200 \text{ ft}^2$

Roof wind force, $P'_{12} = q_2 A_9 = 1,155 \text{ lbs}$

where $A_9 = \text{effective tributary area to wind} = 27.5 \text{ ft}^2$

Total wind force $P_w = P'_{11} + P'_{12} = 9,555 \text{ lbs.}$

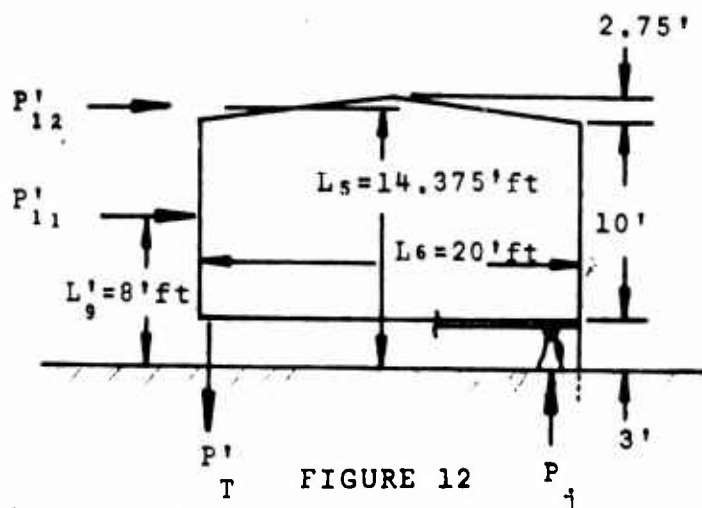


FIGURE 12

Overturning moment of enclosure (M_3'')

As in equation (31), for $L_4 = 8$ ft and $L_5 = 14.375$ ft

$$M_3'' = P_{11}' L_4 + P_{12}' L_5 = 83,803 \text{ ft-lbs}$$

Hold down force (P_T)

$$P_T = \frac{M_3''}{L_6} = 4,190 \text{ lbs}$$

where $L_6 = 20$ ft

Compressive force to jacks (P_j) due to wind

For the reaction force to P_T , distributed over 3 jacks.

$$P_j = \frac{P_T}{3} = 1,396.7 \text{ lbs/jack}$$

1.12 CLASS I SHIELDED ENCLOSURE - ALUMINUM OPTION

This aluminum option conforms to all Class II design calculations with the exception of the sandwich panel design calculations. This is due to the difference in 7075-T6 aluminum used for the Class II design calculations. The following is a brief summary of results of calculations based on those equations used heretofore for the steel option, and using 6061-T6 aluminum. Refer to drawings for parameter values.

1.12.1 Roof Panels

Stress in panel skin: $f_1' = 11,610$ psi (equation 2)
Shear in panel core: $v = 19.8$ psi (equation 4)
Allowable tension stress (6061-T6): $F_a = 19,000$ psi

1.12.2 Floor Panels

Stress in panel skins: $f_s^2 = 8,244$ psi (equation 2)
Shear in panel core: $v_s^2 = 35.27$ psi (equation 6)

1.12.3 Wall Panels

Flexural stress due to wind: $f_s = 5,649$ psi (equation 2)

Axial stress in wall panel: $f_{a1} = 553$ psi (equation 10)

Allowable axial stress in wall: $F_{a1} = \frac{P_{cr}}{A} = 14,200$ psi
(equation 14)

Combined axial and bending stress evaluation:

$$\frac{f_s}{F_a} + \frac{f_{a1}}{F_{a1}} = .366 < 1.0$$

2.0 CLASS II SHIELDED ENCLOSURE - 7075 ALUMINUM

The design calculations for this class of enclosure are based primarily on the use of 7075-T6 aluminum. Since the allowable stresses of 7075-T6 aluminum are almost identical with those of ASTM-A446 Class C steel, the design calculations for the Class II enclosure conform to the Class I enclosure design (steel option) with the exception of the sandwich panel skins. The skin thickness is greater, however, for the Class II design and thus it can be demonstrated to be adequate for the structural requirements of the enclosure.

This option for the Class II enclosure conforms to the existing Class I and II drawings. Thus, specification references for sections 2.0, 2.1, 2.2, etc. conform to the equivalent subsections of section 1.0.

3.0 CLASS III SHIELDED ENCLOSURE - ALUMINUM

This option for the Class III enclosure conforms to the existing drawings with no modifications.

3.1 HONEYCOMB SANDWICH PANELS

Assumptions: all sandwich panels composed of two .040 in. 6061-T6 aluminum skins and a 1 in. paper honeycomb core.

3.1.1 Roof Panels

Bending moment of panel (M_1)
assuming panels analyzed by beam theory

$$M = \frac{q' L^2}{8} \quad (\text{in-lbs}) \quad (1)$$

where q' = uniformly distributed load (psi)
 L = beam span (in.) or equivalent
 M = bending moment (in-lbs) per unit width of section analyzed.

For $q_1 = .403 \text{ psi}$ (58 psf)
 $L_1 = 120 \text{ in.}$

$$M_1 = \frac{1}{8} q_1 L_1^2 = 725 \text{ in-lbs}$$

Stress in panel skins (f'_1)

$$f' = \frac{M}{td} \quad (\text{psi}) \quad (2)$$

where t = panel skin thickness (in.)
and d = distance between skin centroids (in.)

For $M = M_1$, $t = .040 \text{ in.}$, and $d = 1.04 \text{ in.}$;

$$f'_1 = \frac{M_1}{td} = 17,429 \text{ psi}$$

Minimum allowable tension or compression stress (F_{a1}) for fully stiffened elements is

$$F_a = .543 F_y \quad (3)$$

where F_y = tension yield stress

For 6061-T6 aluminum, $F_y = 35,000$ psi

thus $F_{a1} = 19,000$ psi

and the panel skin thickness is adequate
since $f'_1 < F_{a1}$.

Shear in panel core (v'_1)

$$v' = 1.67 \frac{qa}{H + T} \quad (\text{psi}) \quad (4)$$

where a = unsupported span (in)
 H = total panel thickness (in)
 T = core thickness (in)

For $q = q_1$, $a_1 = 120$ in, $H = 1.08$ in, $T = 1$ in

$$v'_1 = 1.67 \frac{q_1 a_1}{H + T} = 38.8 \text{ psi}$$

3.1.2 Floor Panels

Bending moment of floor panels (M_2)

Using equation (1) for $q_1 = q_2 = 1.11$ psi (160 psf)
and $L'_1 = L'_2 = 60$ in.

$$M_2 = \frac{1}{8} q_2 L'^2_2 = 500 \text{ in-lbs.}$$

Stress in panel skin (f'_2)

Using equation (2) for $M = M_2$

$$f'_2 = \frac{M_2}{td} = 12,007 \text{ psi}$$

Since all panel skins are of identical thickness and
the above stress (f'_2) $< F_{a1}$, the floor panel skin
thickness is adequate.

Shear in floor panel core (v'_2)

Using equation (4) for $q = q_2$, $a_2 = 60$ in.

$$v'_2 = 1.67 \frac{q_2 a_2}{H + T} = 53.5 \text{ psi}$$

3.1.3 Wall Panels

Assumptions: Panels are bearing walls for roof load, with two loading conditions;

- A. Bending due to wind combined with axial load due to roof dead loads.
- B. Axial load due to roof dead and live loads, with no wind.

Load Condition (A)

Wind load (q_s)

The basic wind load equations, adjusted for building shape and gust effects, is

$$q = 0.0042 s^2 \text{ (lbs/ft}^2\text{)} \quad (5)$$

where s = wind speed (mps)

Thus for a 100 mph wind,

$$q_s = .0042 s_1^2 = 42 \text{ psf (.292 psi)} \quad (6)$$

Bending moment on wall panels for loading condition A. (M_s)

Using equation (1) for $q = q_s$ and $L' = L_s = 120 \text{ in.}$

$$M_s = \frac{1}{8} q_s L_s'^2 = 526 \text{ in-lbs.}$$

The adjusted bending stress for combined axial and bending stress defined by (7.),

$$\psi = \frac{\psi_o}{1 - \frac{P}{P_{cr}}} \quad (7)$$

where ψ_o = bending stress

P = applied axial load

P_{cr} = euler critical buckling load defined by

$$P_{cr} = \frac{\pi^2 D}{l^2 \left(1 + \frac{\pi l^2 D}{l^2 U} \right)} \quad (8)$$

where D = panel stiffness (lbs-in² per in. of width)

U = shear stiffness (lbs/in per in. of width) as defined in section 1.1.3

l = unsupported length of column (in.)

Combining the roof dead load and wall dead load per inch of width of wall, $P_1 = 12$ lbs. per in. of width.

For $l_1 = 120$ in, $D = 213 \times 10^3$ lbs-in², and $U = 6,975$ lbs/in

$$P_{cr} = 143 \text{ lbs/in of width}$$

Thus for $\psi_0 = f'_3$, using eq. (2) for $M = M_3$;

$$\psi_0 = f'_3 = \frac{M_3}{td} = 12,644 \text{ psi}$$

and

$$\psi = \frac{f'_3}{1 - \frac{P_1}{P_{cr}}}$$

therefore section analyzed is adequate since $\psi < F_{a_1}$

Load Condition (B)

Axial stresses in panel skins due to roof live and dead loads (f_{a_1})

$$f_a = \frac{P}{A} \quad (9)$$

where $A = 2bt$ = area cross section perpendicular to applied force P

and b = width of section analyzed.

Thus, for $P_2 = 36.3$ lbs/in of width, and $A_1 = 2b_1t = .08$ in where $b_1 = 1$ in.

$$f_{a_1} = \frac{P_2}{A_1} = 453 \text{ psi}$$

Allowable axial stress per "The Aluminum Association" specification is determined by,

$$F'_a = \frac{53 \times 10^6}{(l/r)^2} \quad (10)$$

where $r = \sqrt{\frac{I}{A}}$ = radius of gyration
 for $l_2 = 120$ in and $r = \sqrt{\frac{I}{A}} = 0.52$ in.
 $F'_a = 995$ psi

Thus, section analyzed is adequate since $f_{a_1} < F'_a$

3.2 EXTRUSIONS

3.2.1 Panel Edge Extrusion

Assumption: Most critical condition assumed to be at edge extrusion for wind load and roof dead load on wall panels.

Bending moment of edge extrusion assuming top and bottom edges rigidly fixed (M'_1)

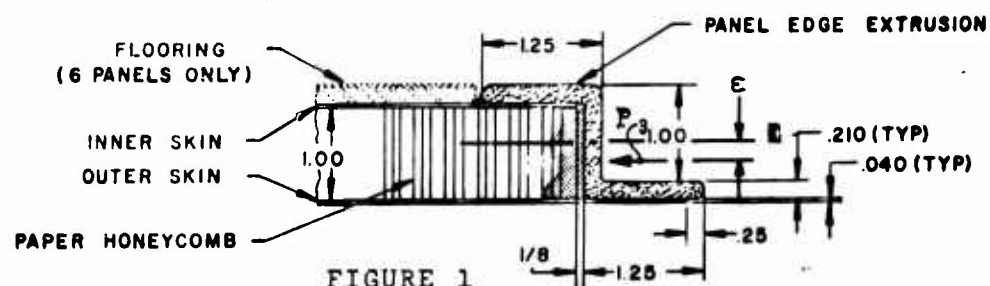


FIGURE 1

$$M'_1 = \frac{q L^2}{12} - P_e \quad (11)$$

where L = moment arm, e = eccentricity of applied force
 for $q = q_1 = .403$ psi, $L_1 = 120$ in, $e = .125$ in. and
 $P_3 = q_1 b'_1 = 32.6$ lbs/in where b'_1 = width of
 tributary load area = 81 in.

$$M'_1 = \frac{q_1 L_1^2}{12} - P_3 e = 479 \text{ in-lbs.}$$

Bending moment of panel edge extrusion assuming panel simply supported on two edges (M''_1).

$$M''_1 = P L' \quad (12)$$

For the moment in the flange, $P_4 = R_1$ = reaction force
 in extrusion due to the wind force on wall panel.

For, $P_1 = R_1 = q, b_2' = 17.5 \text{ lbs/in}$ where $b_2' = 60 \text{ in.}$
and $L_1' = 1.145 \text{ in.}$

$$M_1'' = P_1 L_1 = 20.0 \text{ in-lbs.}$$

Flexural stress in panel edge extrusion (f_1) assuming simply supported edge condition.

$$f = \frac{M}{S} \quad (13)$$

where $S = \text{section modulus (in}^3\text{)}$

For $S_1 = \frac{b_1 k_1^2}{6} = .0074 \text{ in}^3$ where $k = \text{equivalent beam depth.}$
(of section analyzed) and $k_1 = .21 \text{ in.}$, and $b = 1 \text{ in.}$

$$f_1 = \frac{M_1''}{S_1} = 2,726 \text{ psi}$$

Thus, section is adequate since $f_1 < F_{a1}$

Required thickness of panel edge extrusion (k_1') assuming edges fixed.

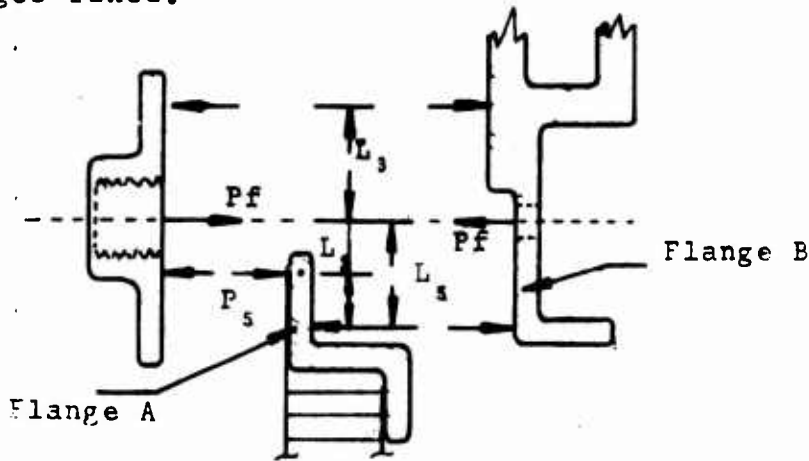


FIGURE 2

$$k_1' = \sqrt{\frac{6M}{F_a b}} \quad (14)$$

From Figure 2, for wind loads,

$$k_1' = \sqrt{\frac{6M_1 \alpha}{F_a b_1 w}} = .24 \text{ in. for 6061-T6 aluminum}$$

where w = wind factor = 1.33

$b_1 = 1$ in.

and $\alpha = 0.5$, since moment M'_1 is shared between panel edge and edge extrusion.

3.2.2 Edge Extrusion

Maximum moment in flange B of edge extrusion (M'_2)

Using eq. (12), for $L'_5 = 1.12$ in.

$$M'_2 = P_5 L'_5 = 536.4 \text{ in-lbs.}$$

where $P_5 = \frac{M'_1}{L_2} = 479 \text{ lbs/ } L_2 = 1 \text{ in.}$

Required minimum thickness for flange B (k'_2)

Using eq. (14), for 6061-T6 aluminum

$$k'_2 = \sqrt{\frac{6 M'_2}{F_{a2} b_1 w}} = .36 \text{ in.}$$

and for 7075-T6 aluminum

$$k'_2 = \sqrt{\frac{6 M'_2}{F_{a2} b_1 w}} = .25 \text{ in.}$$

where $F_{a2} = 39,200$ psi allowable stress for 7075-T6 aluminum.

Required minimum thickness of edge extrusion tube wall (k'_3).

Using eq. (14), for wind loads,

$$k'_3 = \sqrt{\frac{6 M'_1 \alpha}{f_{a1} b w}} = .24 \text{ in.}$$

where $b_1 = 1$ in., $w = 1.33$, and $\alpha = .5$ (moment sharing).

Maximum moment in edge extrusion acting as a load distributing beam (M'_2)

Concentrated load from roof beams (P_6)

$$P_6 = q_1 A_2 = 4,524 \text{ lbs.}$$

where $A_2 = 120 \text{ in} \times 73.6 \text{ in} = 8,832 \text{ in}^2$

Distributed load (q_1') on wall panel from concentrated roof load (P_6),

$$q_1' = \frac{P_6}{L_6'} = 37.7 \text{ lbs/in} \quad (15)$$

where $L_6' = 120 \text{ in.}$

Thus, the maximum moment (M_2')

$$M_2' = 0.1 q_1' (L_7')^2 = 54,288 \text{ in-lbs.} \quad (16)$$

where $L_7' = 120 \text{ in.}$

Flexural stress in edge extrusion (f_2)

Using eq. (13)

$$f_2 = \frac{M_2}{S_2} = 19,813 \text{ psi}$$

Where $S_2 = 2.76 \text{ in}^3$ for edge extrusion.

Thus, section is adequate since $f_2 \approx F_{a1}$, for 6061-T6 aluminum.

3.2.3 Interior Seam Cover Extrusion

Assumption: Extrusions used on roof considered most critical.

Bending moment of extrusion due to roof load (M_3'')

Using equation (12)

$$M_3'' = P_7 L_8' = 38 \text{ in-lbs.}$$

where $P_7 = q_1 b_3' = 50.7 \text{ lbs/in.}$

where $b_3' = 126 \text{ in.}$

and $L_8' = .75 \text{ in.}$

Required thickness of cover extrusion

Using eq. (14),

$$k_4' = \sqrt{\frac{6 M_3'}{f_{a_1} b_1}} = 0.11 \text{ in.}$$

for 6061-T6 aluminum.

3.2.4 End-Section Edge Extrusion

Structural integrity of the basic end-section is provided by diaphragm action of the corrugated sandwich. Edge extrusions function mainly as diaphragm flanges and as stiffening elements for handling and erection. During diaphragm action the edge extrusions carry small loads, relative to their strength, and stress calculations are unnecessary. Handling and erection stress will depend on equipment and methods.

3.2.5 Roof and Floor Beam Flange Extrusions

See Section 3.3. Beams

3.3 BEAMS

3.3.1 Roof Beams

Assumption: Beam section height varies from 6 in. at mid-span to 4.25 in. at each end. Calculations are based on the section of height where parameter is most critical.

Bending moment of beam (M_4)

Using eq. (1); for $q_1' = q_1 b_1' = 48.36 \text{ lbs/in.}$, $b_1' = 120 \text{ in.}$ and $L_1' = 182 \text{ in.}$

$$M = \frac{q_1' L_1'^2}{8} = 20,235 \text{ in-lbs.}$$

Maximum bending stress (f_3)

Using equation (13) for $S = I/c$ section modulus (in^3)
 where I = moment of inertia of cross section about
 neutral axis (in^4)
 c = distance from neutral axis to the extreme
 fiber (in)

At mid-span (depth of beam = 6 in), $I_1 = 16.7 \text{ in}^4$ and
 $c = 1/2 d = 3 \text{ in}$.

where d = depth of beam; $S_1 = 5.56 \text{ in}^3$

Thus,

$$f_s = \frac{M_s}{S_s} = 36,013 \text{ psi}$$

Therefore, the required alloy tension yield stress is
 $f_s \times \text{safety factor of } 1.65 = 59,421 \text{ psi}$

This would necessitate the use of alloy 7075-T6 aluminum
 for beam flanges and webs.

Web shear of roof beams evaluated at end of beam (v_1)

$$v = \frac{R}{ht_w} \text{ (psi)} \quad (17)$$

where,

R = beam reaction force (lbs)
 h = web height (in.)
 t_w = sum of web thickness

For, $h_1 = 3.75 \text{ in}$, $t_{w1} = .20 \text{ in}$. and $R_2 = q_1 A_3 = 4,498$

where A_3 = tributary load area = $93 \times 120 = 11,160 \text{ in}^2$

$$v = \frac{q_1 A_3}{h_1 t_{w1}} = 5997 \text{ psi}$$

The allowable web shear, where $2h_1/t_{w1} = 37.5 < 39$ is
 12,000 psi, and thus web is adequate for shear.

River shear (V_{r1})

$$V_r = \frac{m R Q}{n I} \text{ (lbs) per rivet} \quad (18)$$

where m = rivet spacing (in)
 n = number of rows of rivets
 Q = statical moment of inertia (in^3)

For $m_1 = 3$ in, $n_1 = 2$, $Q_1 = 2$

$$V_{r1} = \frac{m_1 R_2}{n_1 I_1} Q_1 = 808 \text{ lbs/rivet}$$

Thus, in accordance with "The Aluminum Association" specifications (8), the required rivet expected shear strength is 38,916 psi.

The rivet-web bearing stress is for 6061-T6 rivets is 32,320 psi.

The allowable bearing stress is 34,000 psi and since the above is less than the allowable, the section is adequate.

Note: If beams are of 6061-T6 aluminum, the flanges must be at least 0.40 in. thick and the webs at least 0.20 in thick with the height of the beam varying from 5.25 in to 7 in at mid-span. The maximum bending stress then becomes, for $S_x = 10.65 \text{ in}^3$, using equation (13)

$$f_x = \frac{M_x}{S_x} = 18,801 \text{ psi}$$

compared to the allowable stress for 6061-T6 of 19,000 psi.

3.3.2 Floor Beams

Bending moment of beam (M_5)

Using eq. (1), for $q'_3 = q_2 b'_5 = 66.6 \text{ lbs/in}$
(for $b'_5 = 60 \text{ in.}$)

and $L'_{10} = 90 \text{ in.}$

$$M_5 = \frac{q'_3 L'^2_{10}}{8} = 67,493 \text{ in-lbs.}$$

Maximum bending stress (f_5)

Using eq. (13), for $M = M_5$, $I_2 = 24.95 \text{ in}^4$,
 $c = 1/2 d = 3 \text{ in.}$

Thus $S_5 = 8.32 \text{ in}^3$ and

$$f_5 = \frac{M_5}{S_5} = 8,112 \text{ psi}$$

since the allowable stress for 6061-T6 aluminum is $F_{a1} = 19,000 \text{ psi}$, the section is adequate.

Web shear of Floor Beam evaluated at jack mount (v_2)

Using equation (17), for $h_2 = 5.5 \text{ in}$, $t\omega_2 = .20 \text{ in}$. and $R_3 = q_2 A_1 = 2,997 \text{ lbs}$, where $A_1 = 60 \text{ in.} \times 45 \text{ in.} = 2,700 \text{ in}^2$

$$v_2 = \frac{q_2 A_1}{h_2 t\omega_2} = 2,725 \text{ psi}$$

The allowable shear, where $2h_2/t\omega_2 = 55$ is $10,155 \text{ psi}$ and thus section is adequate for load in shear.

Rivet shear (V_{r2})

Using eq. (18), for $Q_2 = 4.3 \text{ in}^3$

$$v_{r2} = \frac{m_1 R_4 Q_2}{n_1 I_2} = 775 \text{ lbs/rivet}$$

Thus, in accordance with "The Aluminum Association" specification (8), the required rivet Expected Shear Strength is $37,316 \text{ psi}$.

The rivet web bearing stress for 6061-T6 rivets is $31,000 \text{ psi}$.

Allowable bearing stress for 6061-T6 rivets is $34,000 \text{ psi}$, therefore the section is adequate.

3.4 WEATHER PROTECTION ROOF

Assumption: The roof cover fabric supports only the roof live load (25 psf). Protection roof low profile allows consideration of roof live load only - no wind load consideration. Sag angle assumed 15° min .

3.4.1 Cover Fabric

Fabric Tear Resistance (T_f) assuming most critical condition at max. sag angle.

$$T_f = \frac{q'}{\sin \theta} = (\text{lbs/in}) \quad (19)$$

where θ = sag angle

for θ min. = 15° and $q' = q_4 b'_6 = 10.16 \text{ lbs/in}$

where $q_4 = .174 \text{ psi (25 psf)}$ and $b'_6 = 58.5 \text{ in}$

thus,

$$T_f = \frac{q_4}{\sin \theta} = 39.2 \text{ lbs/in}$$

3.5 END-SECTION

3.5.1 Basic End-Section Panel

Assumption: For the wind load bending moment the panel spans 10 ft. between floor and roof panels. Since this section is much stronger than the side wall panels (aluminum core vs. paper honeycomb core), stresses are correspondingly low and thus the section is adequate by comparison for wind loads.

For axial loads (roof dead and live load + panel weight), the end section panels act as vertical diaphragm or deep beam, supported by wall return section of end-section at corners as shown in Figure 3 on the following page.

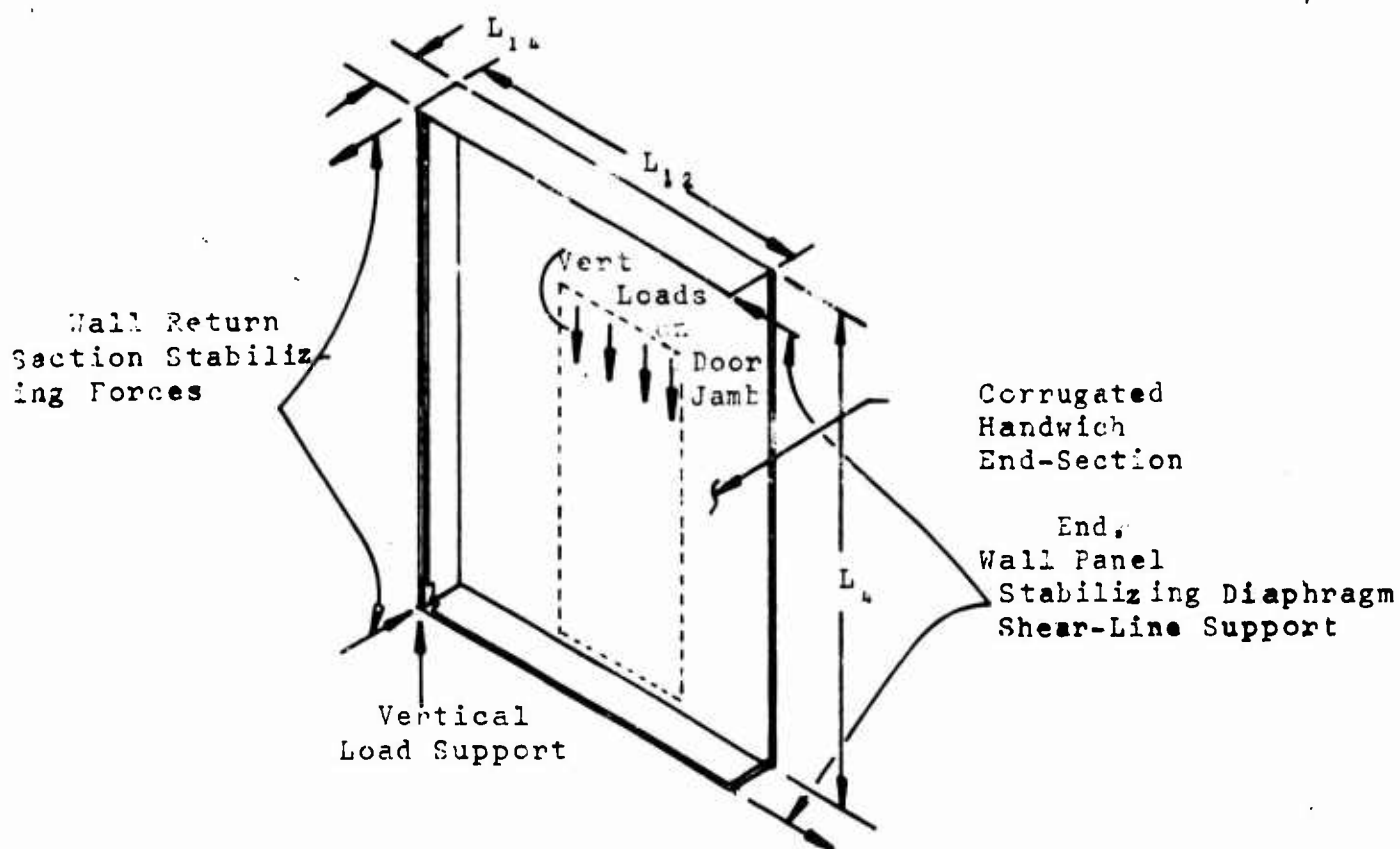


FIGURE 3

Skin Diaphragm Shear For Critical Section

Critical section is over door. Total shear at jamb-line,

$$V = q' L' \quad (20)$$

For $q'_5 = q_1 b'_7 + q_5 b'_8 = 11.8 \text{ lbs/in}$

where $q_5 = .0556 \text{ lbs/in}$, $b'_7 = 12 \text{ in.}$, $b'_8 = 96 \text{ in.}$,

and $L'_{11} = 66 \text{ in.}$

Thus,

$$V_1 = q'_5 L'_{11} = 779 \text{ lbs}$$

APPENDIX IV
PERMANENT ENCLOSURE
DRAWINGS

Unit Shear Stress in Skins (v'_1)

$$v' = \frac{V}{A} \quad (21)$$

For $V = V_1$ and $A_s = 2 t k_2 = 2.16 \text{ in}^2$

where $k_2 = 27 \text{ in}$, $t = .04 \text{ in}$. (combining both skins)

$$v'_1 = \frac{V_1}{2tk_2} = 360 \text{ psi}$$

The allowable shear (for 6061-T6 aluminum) is 12,000 psi, therefore, section is adequate.

Stabilizing Diaphragm Shear (at roof and floor intersections)
(V_{s1})

$$V_s = \frac{VL'}{L} \text{ (lbs)} \quad (22)$$

where V = total shear load

For $V_2 = q'_5 L'_{12} = 1,065 \text{ lbs}$ where $L'_{12} = 90 \text{ in}$.

$L_4 = 120 \text{ in}$. and $L'_{13} = \frac{1}{2} L'_{12} = 45 \text{ in}$.

$$V_{s1} = \frac{V_2 L'_{13}}{L_4} = 399.4 \text{ lbs}$$

Unit Shear Stress in Stabilizing Diaphragm (v'_2)

Using eq. (21), for $V = V_{s1}$, and $A_6 = 2 t k_3 = .96 \text{ in}^2$

where $k_3 = 12 \text{ in}$., $t = .04 \text{ in}$.

$$v'_2 = \frac{V_{s1}}{2tk_3} = 416 \text{ psi}$$

The allowable shear for 6061-T6 aluminum is 12,000, thus, section is adequate.

Wall Return Section Stabilizing Forces

The wall return shear is identical with the maximum shear in the 7.5 ft wide wall panel and is therefore, by comparison, adequate.

The return section stabilizing shear is;

Using equation (22), for $V = V_2$, $L_4 = 120$ in. and $L'_{14} = 12$ in.

$$V_{s_2} = \frac{V_2 L'_{14}}{L_4} = 106.5 \text{ lbs}$$

This shear force is resisted by the connection between wall return and main wall framing extrusion at roof and floor lines.

3.6 PANEL FASTENERS

3.6.1 Required Fastener Tensile Capacity (P_f)

From Figure 2

$$P_f = \frac{P_5 (L_2 + L_3)}{N L_3} = 2586.6 \text{ lbs} \quad (23)$$

where $L_3 = 1.25$ in. and $N = 1$ fastener/3 in.

3.7 FLOORING

Upon further definition of puncture loads, specific calculations for puncture resistance and load distribution can be made.

3.8 JACKS

No specific structural calculations required.

3.9 SKIRTS

No specific structural calculations required.

3.10.1 Vertical Door Jamb

Assumption: Wind load considered to be most critical.

Bending Moment of Door Jamb (M_6)

Uniform load on door jamb acting as vertical beam

$$q'_6 = q_3 \quad b'_9 = 9.63 \text{ lbs/in}$$

where b'_9 = tributary width for wind load = 33 in.

Using equation (1), for $L'_{15} = 120$ in.

$$M_6 = \frac{1}{8} q'_6 L'^2_{15} = 17,340 \text{ in-lbs}$$

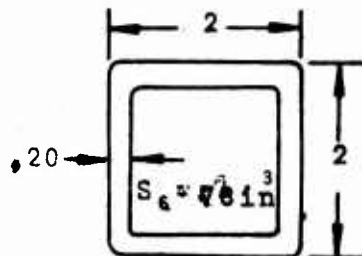


FIGURE 4

Flexural Stress in Door Jamb (f_6)

Using equation (13), for $S_6 = \frac{I_3}{c} = .78 \text{ in}^3$

Where $I_3 = .78 \text{ in}^4$ and $c = \frac{1}{2} d$ for $d = 2 \text{ in.}$

$$f_6 = \frac{M_6}{S_6} = 22,231 \text{ psi}$$

The allowable stress for 6061-T6 aluminum is 25,333 psi (assuming a 1/3 increase for wind load). Thus section is adequate for 6061-T6 aluminum.

3.11 ENCLOSURE ANCHORING

3.11.1 Overturning Forces

Total Wind Force on Enclosure (maximum load) (P_w)
(neglecting minimal roof wind forces)

$$P_w = q_3 A_7 = 13,440 \text{ lbs} \quad (24)$$

where $A_7 = 320 \text{ ft}^2$

Overturning Moment of enclosure (M_4')

Using equation (12), for $L' = L = \text{moment arm}$

$$M_4' = P_w L_5 = 107,520 \text{ ft-lbs}$$

where $L_5 = 8 \text{ ft}$

Hold-down Force (P_T)

$$P_T = \frac{M_4}{L_6} = 7.168 \text{ lbs} \quad (25)$$

where $L_6 = 15 \text{ ft}$

Compressive Force to Jacks (P_j) due to wind

For the reaction force to P_T , distributed over 7 jacks,

$$P_j = \frac{P_T}{7} = 1.024 \text{ lbs/jack} \quad (26)$$

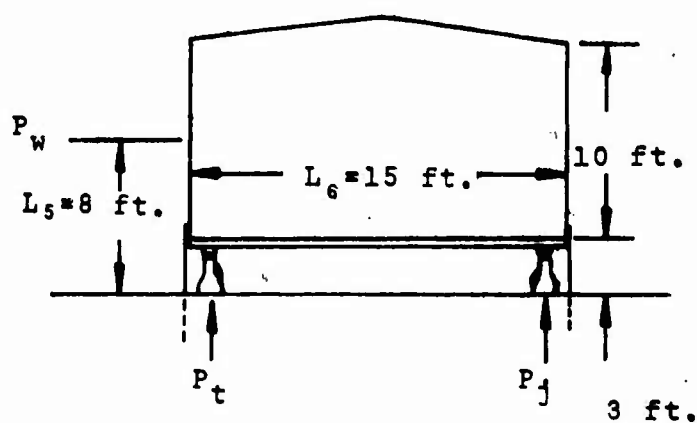


FIGURE 5

DESIGN NOMENCLATURE

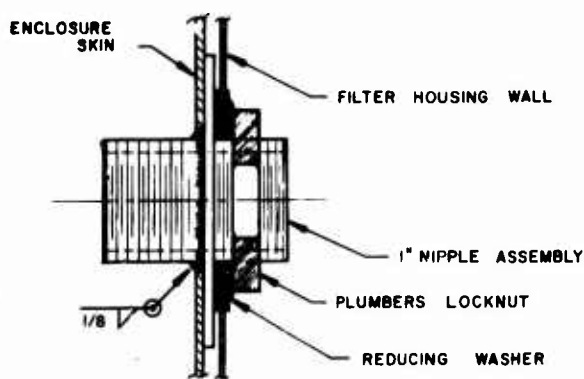
- a = unsupported span (plate theory) (in)
- A = cross sectional area analyzed
- b = width (in) of beam, column, or equivalent section analyzed
- b' = width of tributary loading area
- C_c = column constant
- d = distance between skin centroids (in)
- D = flexural coefficient dependent upon material and support conditions (psi/inch of width)
- E = modulus of elasticity
- f = flexural stress (psi)
- f_a = axial stress
- F_a = allowable axial stress (psi)
- F_b = allowable bending stress
- F_y = the material yield point stress (psi)
- G_c = core shear modulus (psi)
- H = total panel thickness (in)
- I = rectangular moment of inertia with respect to neutral axis, (in.⁴)
- I' = moment of inertia for a beam or equivalent
- k = depth (in) of beam, column, or equivalent section analyzed
- K = effective length factor
- l = unsupported length (in) of column or equivalent
- L = the moment arm
- L' = beam span or equivalent
- L'' = unbraced length of beam compression flange (in)

M = bending moment
 N = fasteners per inch
 p = spring constant
 P = applied axial force (lbs/unit width of section analyzed)
 P_{cr} = Euler critical buckling load
 P' = applied force
 q = uniformly distributed load (psi)
 r = radius of gyration, (in)
 R = reaction force
 s = wind speed in mph
 S = section modulus
 t = thickness (in)
 T = core thickness (in)
 U = shear stiffness per in. of width
 v = shear stress
 V = Shear force
 w = wind factor
 x = distance from deflection point to point of applied force
 y = deflection
 z = the separation between the two rows of fasteners
 γ = a constant

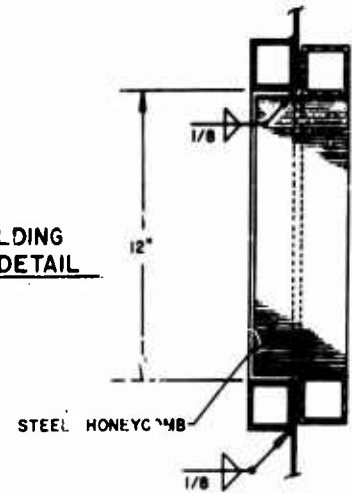


CLASS I & II
40'X100' SHIELDED ENCLOSURE
SECTION, ELEVATIONS, DETAILS

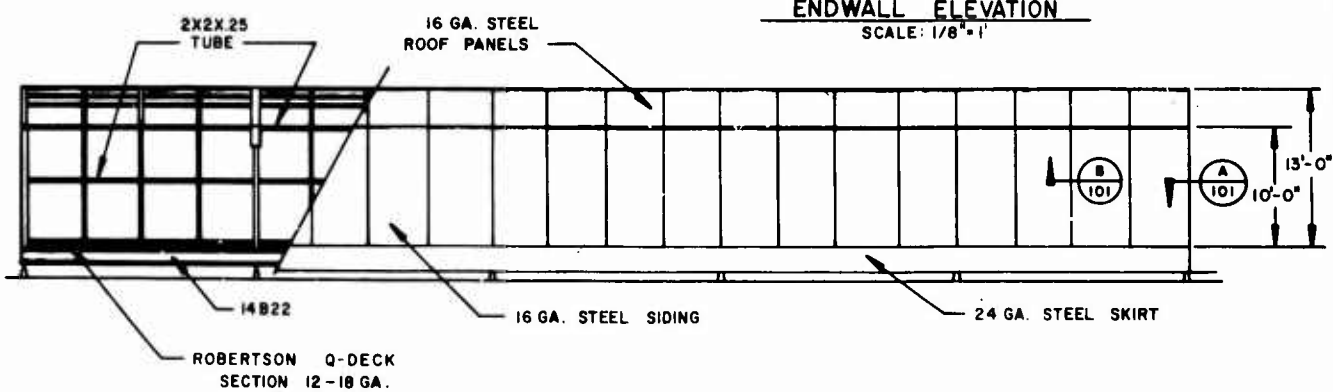
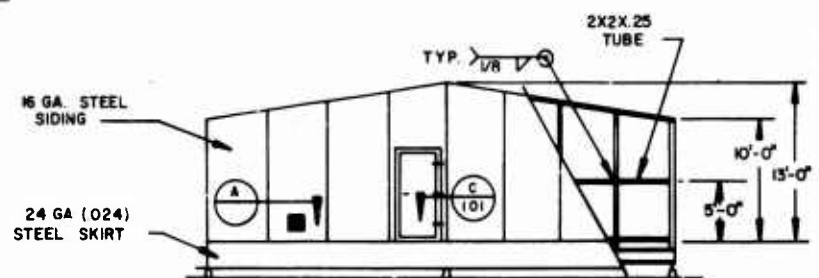
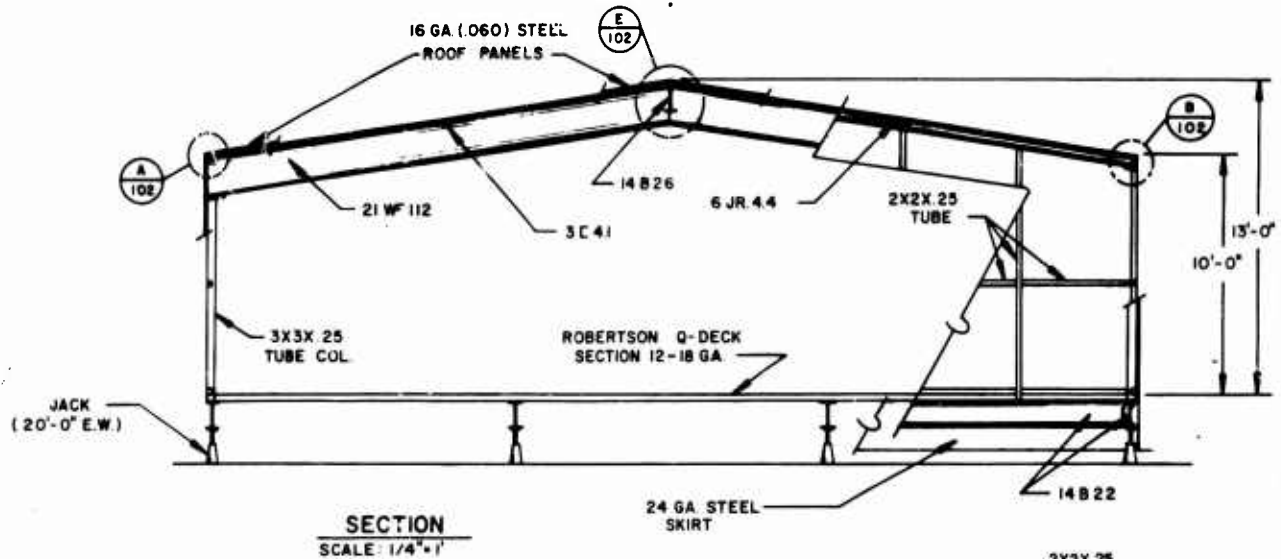
SCALE	DRAWING NO.	SHEET
NOTED	10740-B100	1 OF 4
SPECIFICATION REFERENCE	VOL. UNLESS OTHERWISE SPEC.	
FACT	ORIGINAL	REVISION

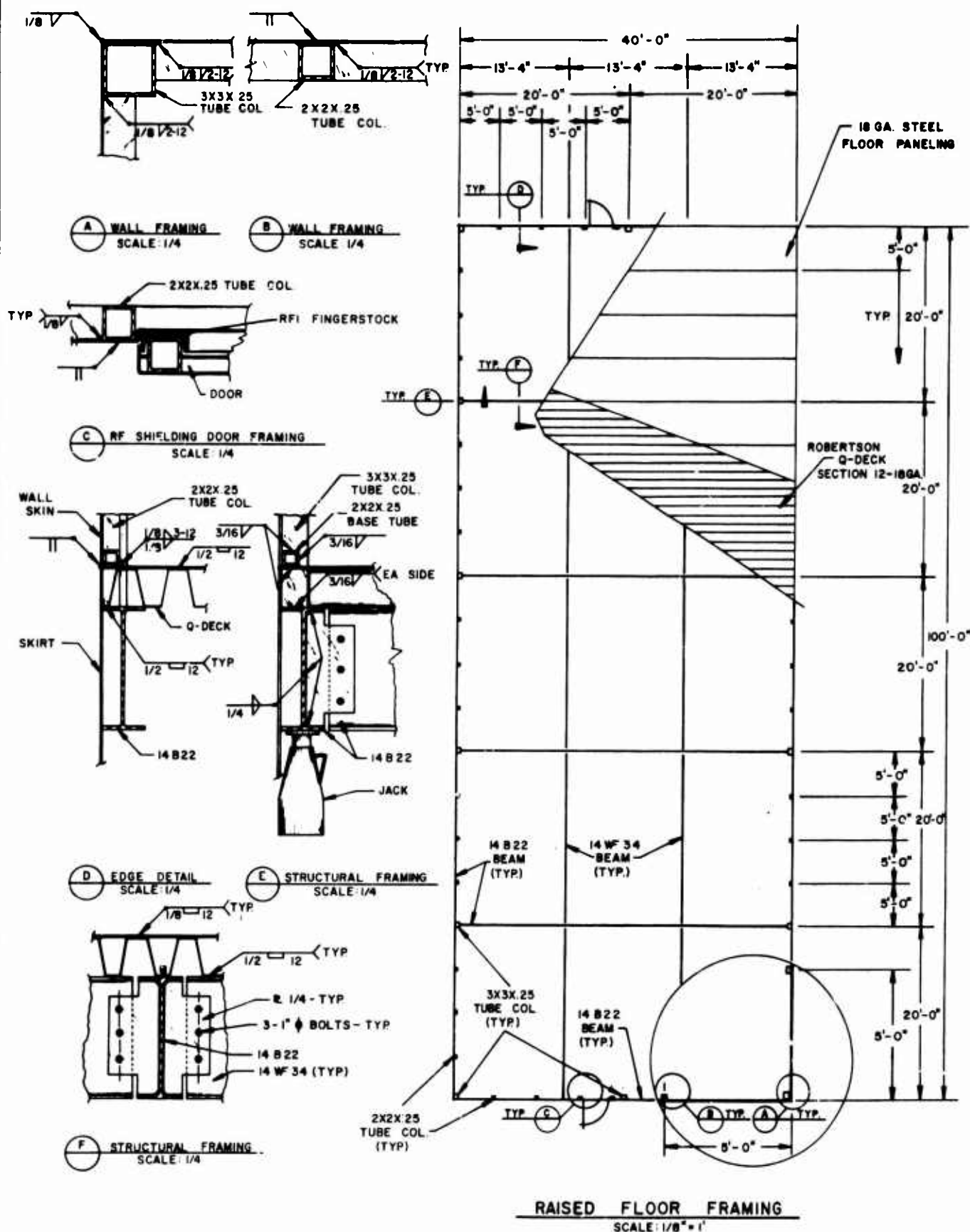


RF SHIELDING
AIR VENT DETAIL
SCALE: 1/4



TYPICAL ELECTRICAL SKIN PENETRATION
SCALE: 1/1

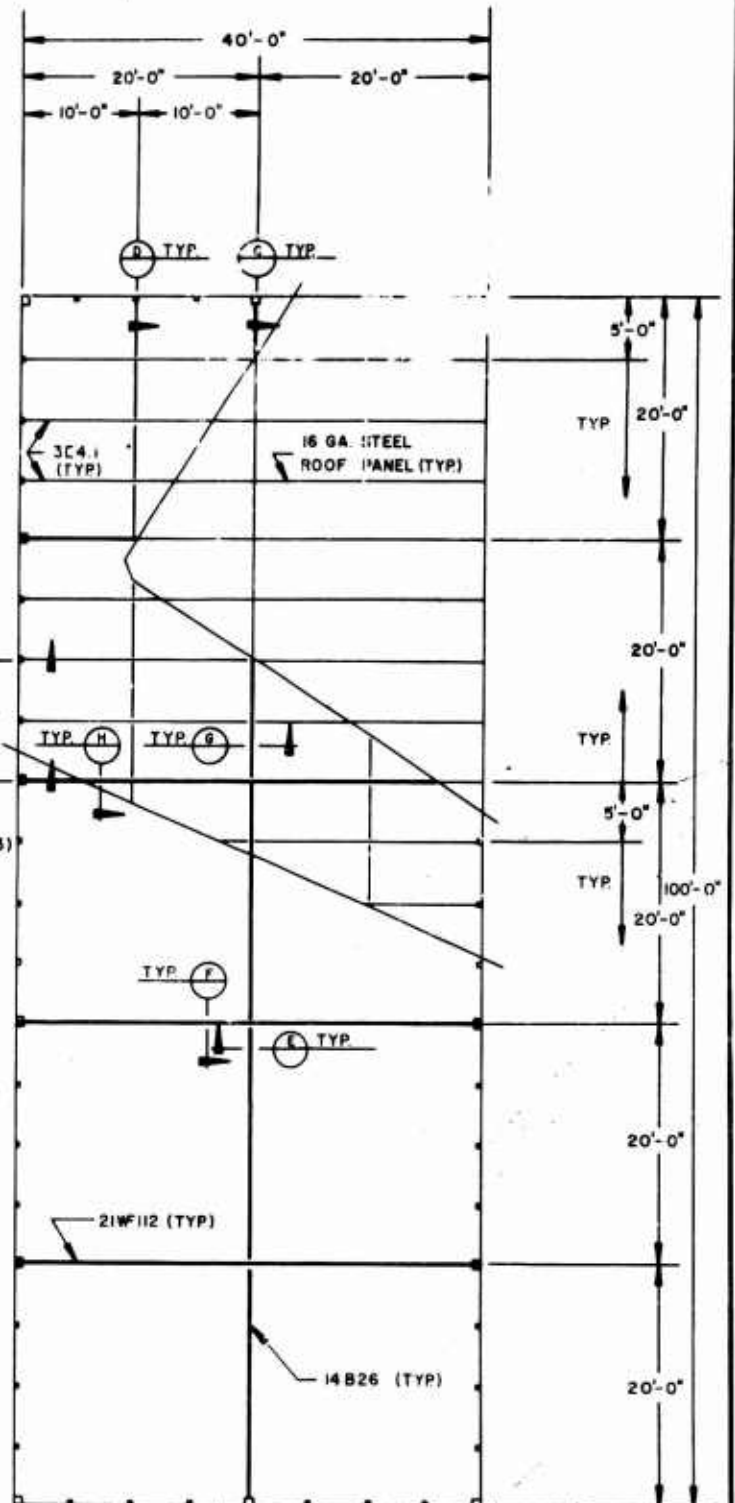
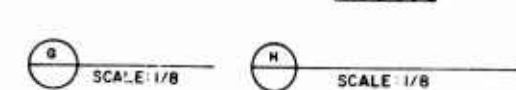
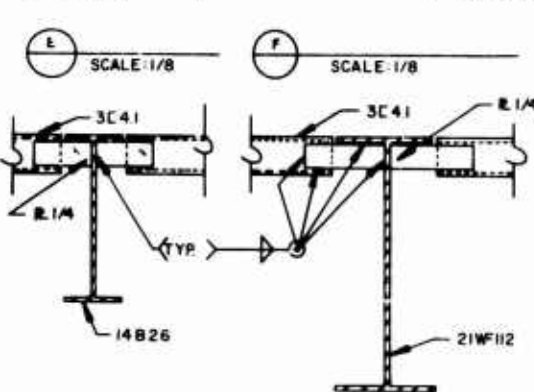
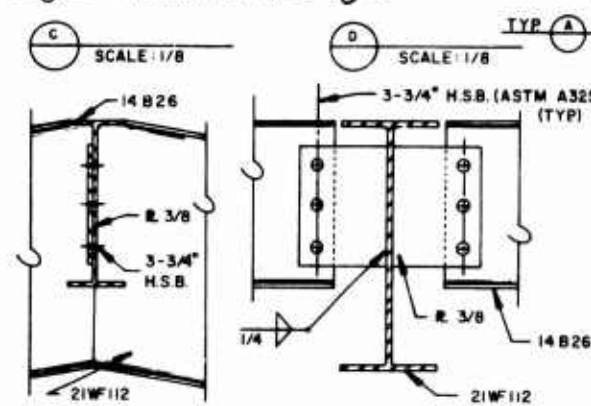
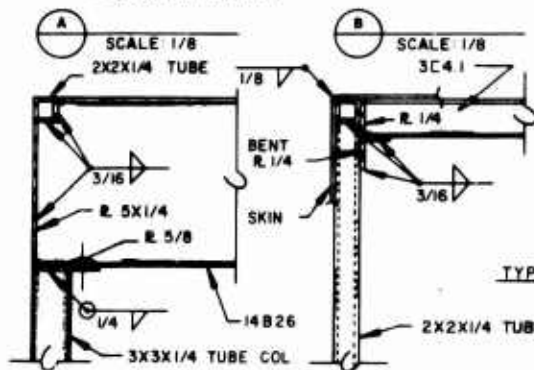
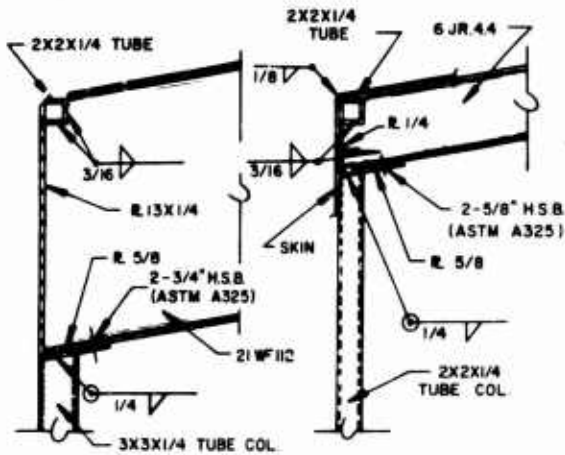






CLASS I & II
ROOF FRAMING & DETAILS

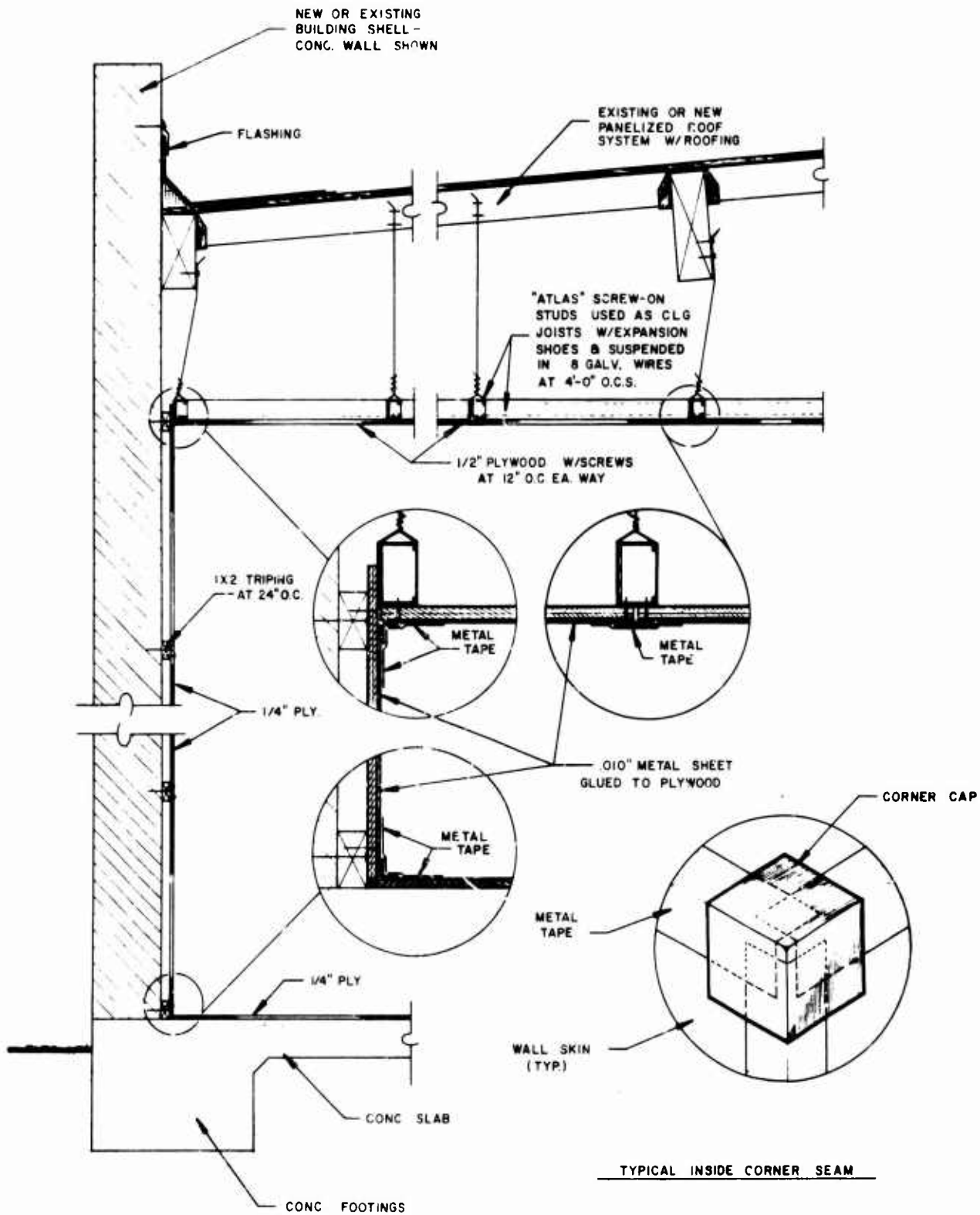
SCALE	NOTED	DRAWING NO.	10740-B102	SHEET OF	3	4
SPECIFICATION REFERENCE:		TOL. UNLESS OTHERWISE SPEC.		FRAC.	DECIMAL	ANGLE



ROOF FRAMING PLAN
SCALE: 1/8" = 1'

CLASS III CONCEPTUAL DESIGN
FOR A SHIELDED PERMANENT ENCLOSURE

SCALE	DRAWING NO.	SHEET	OF
NTS	10740-B103	4	4
SPECIFICATION REFERENCE:		VOL. UNLESS OTHERWISE SPEC.	
FACT.	DETAILS	ANAL.	



NOTE ALL ABOVE METAL IS COPPER OR ALUMINUM

APPENDIX V

REFERENCES

1. MIL-E-8881A
2. NSA Specification 65-6
3. MIL-STD-285
4. Attachment 3, Exhibit A (Statement of Work) of Contract F33615-68-C-1206
5. S. A. Shelkunoff, Antennas Theory and Practice
6. G. P. Rothhammer (ed.) "RFI Principles, Instrumentation, and Measurement Procedures", Stoddart Electro Systems
7. "Design and Analysis", Aircomb Div., Douglas Aircraft Co., 1963.
8. "Aluminum Association Specification"
9. D. Moehring "The Properties of Magnetic Metals and Powdered-Iron Cores at High Frequencies". USAF Translation F-TS-T-47-RE, 1947.
10. Brush, Shulz, and Jorgenson; IEEE Transactions on EMC, Vol. 10, P. 67; 1968.
11. S. A. Shelkunoff, Electromagnetic Waves, Van Nostrand, 1943.

APPENDIX VI

RFI MATERIAL SOURCES

During the course of this project much useful information about a great number of types of materials has been obtained. Many of the companies listed have been contacted to submit samples for testing. A list of companies and their product of interest are as follows:

1. Carey Electronics Engineering Company
Metal Wool Division (copper and Aluminum Wool)
2. Swift Textile Metalizing and Laminating Corporation
(Electrically Conductive Cloth-Test Samples 56, 60, 61)
3. ACS Industries, Incorporated
(Knitted Wire Mesh)
4. RF Communications, Incorporated
(Transportable Communication Shelters)
5. Air Inflatable Products Company
(Rubberized Shielding Materials-Test Sample 63)
6. Lash Laboratories
(Foil Clad Kapton Shielding-Test Samples 41, 42, 70, 71)
7. Newark Wire Cloth Company
(Screening and Wire Cloth Materials-Test Samples 58, 59 and 62)
8. Huyck Metals Company
(Feltmetal-Fiber Metal-Test Sample 72)
9. Brunswick Corporation, Defense Products Division
(Hospital Module System)
10. Dynaloy, Incorporated
(Conductive Paints and Epoxies)
11. Kressilk Products Incorporated
(Wire Cloth)

12. Penberthy
(Radiation Shielding Windows for X Ray)
13. International Steel Company
(RFI Shielded Lindsay Structures)
14. Amerind, Incorporated
(Shielded Enclosures)
15. C. O. Jelliff Corporation
(Wire Cloth and Screening)
16. Tecknit
(Gasket Material-Test Samples 73, 74, 75, 76)
17. Emerson Cuming
(Epoxies, Shielded Rooms-Test Sample 55)
18. Soule Steel
(Urethane filled Temp-Con Steel Panels-Test Sample 102)
19. Russell Industries
(RF Shielding Material)
20. Inland Steel Products Company
(Steel Panels)
21. Woven Structures Incorporated
(Woven Metal Cloth-Test Sample 57)
22. Barry Controls Division of Barry-Wright
(Prefabricated Acoustical Enclosures-Test Enclosure to be received)
23. Primec Corporation
(Shielding Materials-Test Samples 34, 35, 36, 37)

Unclassified
~~Security Classification~~

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